ESTCP
Cost and Performance Report

(UX-0031)

Airborne UXO Surveys Using the Multi-Sensor Towed Array Detection System (MTADS)

July 2005

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ACRONYMS AND ABBREVIATIONS

3-D	three-dimensional
A&E	architectural and engineering
AEC	Army Environmental Center
AFB	Air Force Base
APG	Aberdeen Proving Ground
ATC	Aberdeen Test Center
ATV	all-terrain vehicle
BBR	Badlands Bombing Range
BDU	bomb dispensing unit
BRAC	base realignment and closure
CEHNC	U.S. Army Corps of Engineers, Huntsville Engineering and Support Center
CENWO	Corps of Engineers Northwestern Division Omaha District
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act (commonly known as Superfund)
COG	course over ground
CRADA	Cooperative Research and Development Agreement
CTT	Closed, Transferred or Transferring
DAQ	data acquisition system
DAS	data analysis system
DEM	digital elevation model
DoD	Department of Defense
DOQ	digital orthoquad
EM	electromagnetic
EOD	Explosive Ordnance Detection
EOTI	Explosive Ordnance Technology, Inc.
EPA	Environmental Protection Agency
ERDC	U.S. Army Engineer Research and Development Center
ESTCP	Environmental Security Technology Certification Program
FBO	fixed base operator
FUDS	former used defense sites
GIS	geographic information system
GP	general purpose
GPS	Global Positioning System
GUI	graphical user interface
GX	Geosoft Executables

HAE	height above ellipsoid
HAZWOPR	hazardous waste operation
HE	high explosive
IA	impact area
IDA	Institute for Defense Analyses
MTADS	multisensor towed array detection system
NAD	North American Datum
NRL	Naval Research Laboratory
OE	ordnance and explosives
ORNL	Oak Ridge National Laboratory
ORAGS	Oak Ridge Airborne Geophysical System
OST	Oglala Sioux Tribe
Pd	probability of detection
PI	principal investigator
QA	quality assurance
QC	quality control
RFP	request for proposal
ROC	receiver operating characteristic
RTK	real-time kinematic
SERDP	Strategic Environmental Research and Development Program
STOLS	Surface Towed Ordnance Locater System
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
UXO	unexploded ordnance

ACKNOWLEDGEMENTS

The Airborne MTADS was developed and demonstrated with support of the Environmental Security Technology Certification Program (ESTCP), Project UX-0031. We are grateful for the continual support and encouragement during this project by Dr. Anne Andrews, the UXO Program Coordinator, and Dr. Jeff Marqusee, the ESTCP Director. The program's Principal Investigator was Dr. Jim R. McDonald until his retirement from NRL in November 2001. Subsequently, the principal investigator at NRL has been Dr. Herbert H. Nelson. This project supported three wide-area demonstrations. The results of each of these demonstrations have been reported in a final demonstration report, and the entire project was documented in a project final report.

In the initial demonstration at the Badlands Bombing Range, we were hosted by Mr. Dell Petersen of Ellsworth Air Force Base. Our efforts were coordinated with Ms. Emma Featherman-Sam, of the Oglala Sioux Tribe, who is director of the Badlands Bombing Range Project Office. Inert ordnance was provided by AEC (Mr. George Robitaille) and degaussed by ATC (Mr. Rurik Lodar). These ordnance were installed on site by ERDC (under the direction of Dr. Ernie Cespedes).

In our demonstration at the APG, we were hosted by Mr. George Robitaille, working under the ESTCP Wide Area Survey projects. Site preparation work, survey oversight, and ordnance remediation efforts took place under the direction of Mr. Gary Rowe of ATC.

The demonstrations at the Isleta Pueblo target S1 were coordinated with Mr. Jim Piatt, Environmental Director of the Isleta Pueblo. Inert seed ordnance were again provided by ATC (Mr. Gary Rowe) and implanted by ERDC under the direction of Mr. Tommy Berry.

Mr. Mike Tuley and Mr. Elvis Dieguez at IDA provided analyses of our target reports and demonstration reports at APG and Isleta, and with fresh eyes, wrote critical, comparative reports of the NRL and ORNL airborne survey demonstrations at these sites.

Nova Research, Inc. (Mr. Russ Jeffries, Mr. Glenn Harbaugh, and Dr. Dan Steinhurst) provided important logistics and field survey support.

EOTI (Mr. Wayne Lewallen) provided careful and thorough UXO remediation services following the BBR and Isleta demonstrations.

Finally, we wish to acknowledge the critically important contributions made by AETC Incorporated (particularly Mr. David Wright, Dr. Tom Bell, Mr. Bruce Barrow, Dr. Nagi Khadr, and Dr. Jim McDonald) in the development of the Airborne MTADS, support of its field operations, care and nurturing of the data processing and target analysis suite of software, support of all the field demonstrations, and preparation of the data products.

1.0 EXECUTIVE SUMMARY

1.1 BACKGROUND

Buried unexploded ordnance (UXO) is arguably the most serious and prevalent environmental problem currently facing Department of Defense (DoD) facility managers. Not limited to active military bases and test ranges, these problems also occur at DoD sites that are currently dormant and in areas adjacent to military ranges that belong to the civilian sector or are under control of other government agencies. The amount of land affected is generally agreed to be in excess of 10 million acres in the continental United States. UXO mitigation and remediation requirements assume even more compelling proportions when the DoD lands involve formerly used defense sites (FUDS) or base realignment and closure (BRAC) sites. These sites must be cleaned to an appropriate level and certified as suitable for their intended end use.

With the support of the Environmental Security Technology Certification Program (ESTCP) Project UX-0031, an airborne version of the multisensor towed array detection system (MTADS) vehicular towed array has been developed and demonstrated. The objective of this project was to produce an efficient and economical UXO survey system with production rates and costs appropriate for surveying large tracts of land. While the system we developed is ideally suited to localizing burial caches of ordnance and establishing which areas are uncontaminated, it also retains the MTADS' capability of detecting and locating individual ordnance items the size of 2.75-in rocket warheads (and larger).

The system deploys a linear array of seven Cs-vapor magnetometers spaced at 1.5-m intervals in a forward-mounted boom. The system is certified for operation on all models of the Bell Long Ranger helicopter. Two global positioning system (GPS) units mounted on the forward boom provide positioning and helicopter roll and yaw measurements. A pilot guidance display provides survey progress and platform information in real time. The data acquisition electronics rack is mounted in one of the rear seat positions.

1.2 DEMONSTRATION RESULTS

1.2.1 Badlands Bombing Range

The first demonstration was at the Badlands Bombing Range (BBR), which was used for many years for ground artillery training (105-mm, 155-mm, and 8-in projectiles). The airborne system performance was evaluated against the vehicular MTADS in a 110-acre survey (which included a 10-acre area where inert projectiles were blind seeded). All targets in the vehicular and airborne target reports were dug. The Airborne MTADS then surveyed an additional 1,600 acres. About one half of the targets in this target report were also dug. In the commonly surveyed areas, the vehicular and airborne systems' ordnance detection capabilities were indistinguishable from one another; all inert and live UXO detected in the vehicular survey and analyses were also detected in the airborne survey. The ability to distinguish ordnance from clutter was more difficult with the airborne platform. The airborne survey analyses contain 67% more targets than the vehicular surveys. The high-density data in the vehicular survey enables many non-UXO targets to be excluded from consideration on the basis of shape information that is not available in the much sparser airborne data. The airborne analyses also produce priority

assignments that are skewed toward the priority 1, 2, and 3 categories, again because the shape information in the anomaly signature that the analyst uses is not present to the same degree in the airborne data. The airborne survey production rate was nearly 500 acres per survey day.

1.2.2 Aberdeen Proving Ground

The second demonstration was at the Aberdeen Proving Ground (APG) on five sites containing different ordnance types and densities. Topographies varied from flat, level, grass-covered meadows to trees and brush, wetlands, freshwater ponds, and marine offshore areas. Inert ordnance was seeded into three of the sites, including one area that had not previously been used as a range. Detection of the seed targets varied from very good on the airport site (85% detection with six false alarms per detection to 94% detection with 11.5 false alarms per target) to near zero on a highly cluttered range. Detection of ordnance (81-mm and 105-mm) was difficult in the ponds but straightforward in the offshore areas populated by larger targets. Extensive, preexisting targets were dug on one of the highly cluttered ranges; more than 30% of the recovered targets were ordnance. The Airborne MTADS' performance was measured against blind seeded targets and relative to another airborne survey system fielded by Oak Ridge National Laboratory (ORNL). The Airborne MTADS' production rate on these small sites was about 35 acres/hour.

1.2.3 Isleta Pueblo

The third demonstration was at the Isleta Pueblo in New Mexico on a range used for airborne training during the 1950s. This range has a prominent central bull's eye, which was populated by a high density of buried ordnance and ordnance-related clutter. Areas north and south of the bull's eye were surveyed by the vehicular MTADS. Small (60-mm and 81-mm) and medium (105-mm and 155-mm) seeded targets had also been placed in these 100-acre areas. These areas had a relatively high density of metallic clutter and significant geological interferences. The vehicular survey detection capability for the seeded targets (96% detection with 16 false alarms per hectare) was better than that of the airborne system (64% detection, excluding the 60-mm mortars with 11 false alarms per hectare). The Airborne MTADS and the airborne ORNL survey systems each surveyed about 1,500 acres centered on the bull's eye. Extensive targets were dug from these target reports. The Airborne MTADS' production rate on this desert range approached 60 acres per hour.

1.2.4 Cost Assessment

There are no commercial vendors offering airborne UXO geophysical services. We estimate, based on our production rates and costs, that ultimately the production costs for airborne UXO search services will likely range from $100-$200/acre, depending on the site size and conditions. The Airborne MTADS is appropriate for wide area searches (at least 500 acres, i.e., at least 1 survey day). Many sites will not be able to be completely characterized using the airborne system, however, if 100% coverage is required. Most sites will require some fill-in work by ground-based systems.

1.3 REGULATORY AND STAKEHOLDER ISSUES

The regulatory issues affecting the UXO problem are most frequently associated with the BRAC and FUDS processes involving the transfer of DoD property to other government agencies or to the civilian sector. When transfer of responsibility to other government agencies or to the civilian sector takes place, the DoD lands fall under the compliance requirements of the Superfund statutes. Section 2908 of the 1993 Public Law 103-160 then requires adherence to Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) provisions. The basic issues center on the assumption of liability for ordnance contamination on previously DoD-controlled sites. These regulatory considerations do not apply to active DoD facilities.

The Airborne MTADS is an appropriate technology for addressing the UXO problem in areas where the terrain cannot be traversed on foot, that are dangerous for ground activities, and that are too large to survey economically with vehicular systems. These demonstrations provide data that can be used to demonstrate a statistical probability of success for the detection and characterization of isolated bombing targets or impact areas, ordnance burial caches, or individual ordnance, including a range of medium- and large-sized ordnance. These considerations are important in establishing the value of this approach and in its ultimate acceptance by regulators and the stakeholder community.

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2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY DEVELOPMENT AND APPLICATION

2.1.1 Automated Georeferenced Surveys

The Strategic Environmental Research and Development Program (SERDP), ESTCP, and the U.S. Army Environmental Center (AEC) UXO Advanced Technology Demonstration Programs for nearly a decade have been addressing the need for more modern, automated UXO detection and characterization technologies. These investments have resulted in the development, demonstration, and commercialization of automated site characterization technologies such as MTADS. The original MTADS consists of a tow vehicle and two low self-signature platforms: one for an eight-sensor magnetometer array, the other for a three-sensor, time-domain, electromagnetic (EM) pulsed-induction array.[1] MTADS uses GPS for recording sensor position locations and for survey guidance, and it employs a sophisticated data analysis system. MTADS has demonstrated relatively rapid and efficient surveying of large sites, with commensurate economic benefits, for a wide range of buried UXO items at their maximum likely penetration depths.[2-8] On ranges with relatively uncomplex use histories (i.e., ranges involving the use of similar types of ordnance, such as only air-deployed bombs and practice bombs, or only surface gun-fired projectiles), routine UXO detection probabilities of greater than 95% are often achieved in areas without severe geological interferences. Use of fully integrated GPS enables sensor measurements to be time- and location-stamped so that the survey products are georeferenced digital maps of the survey area for which buried target signals can be analyzed using physics-based fitting algorithms. The survey products are compatible with geographic information system (GIS) mapping technologies. The survey results can thus be permanently archived, used for quality assurance (QA)/quality control (QC) evaluations, organized to support subsequent (including delayed) remediation activities, and used to evaluate or defend the performance of the system if legally challenged. In extended surveys, all of the UXO site characterization activities, including the surveying, target analysis, and preparation of reporting documents to support remediation activities, can be delivered for $400-1,000 per acre, depending on the size and complexity of the site. The MTADS technology (both the vehicular and man-portable platforms) was transitioned to the commercial sector (Blackhawk Geometrics, Inc.) by means of a Cooperative Research and Development Agreement (CRADA)[9] and is currently being used to provide commercial UXO services to the DoD.

This technology has provided a huge step forward in capability, efficiency, and economy for UXO site characterization. The DoD, the U.S. Environmental Protection Agency (EPA),[10] and the Army Corps of Engineers have sanctioned this approach as the preferred technology that should be used by default unless there are mitigating circumstances. While this has been declared the technology of choice, only a fraction of the UXO site characterization activities are currently being carried out using the modern technology. There are purportedly three mitigating circumstances justifying the continued use of Mag and Flag for UXO surveys. These include sites that are too small to justify use of vehicular systems, sites where forest canopies or limited sky visibility precludes the use of GPS, and sites where the surface geology or topology is not suitable for vehicular surveys and that are too small for cost-effective airborne surveys. These three limitations have been addressed by the man-portable MTADS adjuncts, which employ both GPS and acoustic navigation. Under ESTCP Project UX-9811 (Man-Portable Adjuncts for the

MTADS), NRL developed and demonstrated man-portable adjuncts to the vehicular MTADS arrays.[11-13] Both the magnetometer and EM vehicular systems can be implemented with either GPS or acoustic navigation to enable surveying in areas without sky view. These man-portable adjuncts to the MTADS have also been transitioned to the commercial sector through the CRADA with Blackhawk Geometrics.[9] Variants of the NRL man-portable MTADS hardware, as demonstrated for ESTCP, are generally available from several commercial UXO service providers.

One significant limitation of the man-portable systems is that while they have relatively modest deployment and mobilization costs, they invariably are more expensive to operate (on a per-acre basis) than the vehicular systems. Man-portable MTADS survey costs are typically similar to the costs of Mag and Flag UXO survey products.[13] Even given this limitation, use of the man-portable MTADS is preferable because it provides digitally referenced survey products.

For very large sites where the costs associated with UXO surveys formerly precluded any comprehensive action from being undertaken, the Airborne MTADS, described below, has become a low-cost, high production rate option.

2.1.2 The Airborne System

The Naval Research Laboratory (NRL), with the support of ESTCP Project UX-0031, has adapted the vehicular MTADS magnetometry technology for deployment on an airborne platform.[14] The primary objective of this development was to provide a UXO site characterization capability for extended areas that are inappropriate for vehicular or man-portable surveys. Because the sensors on an airborne platform must be deployed farther from the ground surface than those on vehicular or man-portable systems, it is understood that detection sensitivity for single, smaller UXO items is compromised. It has been a goal of the development, however, to retain as much detection sensitivity as possible for individual UXO targets.

Sites appropriate for airborne surveys include those with terrain that would be difficult to survey efficiently with a vehicular system and those that are too extensive to evaluate economically with vehicular or other approaches. Many formerly used ranges dating from World War II (and earlier) are located in areas involving tens or hundreds of thousands of acres with isolated bombing targets or impact ranges. Locations of many of these impact areas (or ordnance burial caches) are either not known or imprecisely known. Some of these areas are located on Native American reservations, while others involve Closed, Transferred or Transferring (CTT) ranges. Therefore, an additional objective of the development was that the final airborne system have survey production rates and costs appropriate for exploring very large sites that would be prohibitively expensive to survey by other techniques.

2.1.3 System Specifications and Requirements

It was realized during our initial modeling studies that by using magnetometer arrays mounted on helicopter platforms, the smallest military ordnance would not be detectable as individual targets. Modeling calculations were carried out to evaluate target signatures as a function of altitude (i.e., the standoff distance between the target and sensor). Helicopter pilots were interviewed to

determine the practical flying limitations for altitude, payload, platform design, and mission endurance that could be expected. We developed and refined the specifications and requirements that became part of our original proposal and the development plan. Table 1 shows a summary of the design specifications from the requirements document in the Airborne MTADS development plan.

Table 1. System Specifications and Requirements for the Airborne MTADS.

Activity	Requirement
Survey flight duration	2 hours (including ferry and calibration time)
Survey speed	10–20 m/sec
Lane spacing	7.5 m (nominal) *
Survey area (single setup)	250 acres
Flights per day	3 (single pilot)
Detection sensitivity	Isolated BDU-33 or 2.75-in warheads
Sensor sensitivity	0.01 nT
Sensor data rate	100 Hz
GPS navigation data rate	20 Hz
GPS sensor position accuracy	5 cm
Data acquisition system (DAQ)	Compatible with vehicular MTADS DAQ
Data analysis system (DAS)	Seamless integration with vehicular data

*Depending on winds and pilot experience

2.1.4 Field Hardware

The Airborne MTADS hardware incorporates an array of seven magnetometers on a platform designed for a Model 206L Bell Ranger helicopter. The sensors are Cs-vapor, full-field magnetometers, Geometrics Model 822A. The specially selected magnetometers are airborne quality. The helicopter with the mounted magnetometer array is shown in Figure 1. All sensors are interfaced to the data acquisition system (DAQ) computer. The DAQ electronics are contained in a rack mounted in the rear starboard seat position in the helicopter. The power distribution interface is also in the rack, as are readouts for all the sensor inputs. On the 9-m boom, the seven sensors are mounted with a 1.5-m horizontal spacing. The sensor positions over the surface of the Earth (latitude, longitude, and height above ellipsoid [HAE]) are determined using satellite-based GPS navigation, employing the latest real-time kinematic (RTK) technology, which provides a real-time position update (at 20 Hz) with an accuracy in the horizontal plane of about 5 cm. GPS satellite clock time is used to time-stamp both position and sensor data information for later correlation.

Figure 1. Airborne MTADS Survey on the Active Recovery Field. (Note the 2-m-high vegetation that stretches from this point to the shoreline.)

Dual GPS antennas (Trimble Zephyrs), deployed on the forward horizontal boom, in addition to providing the position over ground and the height above ellipsoid positions for sensor mapping, provide boom roll-and-yaw attitude information for sensor location corrections. An inclinometer provides the pitch attitude correction, and a fluxgate gradiometer provides three-axis information that can be used to derive aeromagnetic compensation corrections for the magnetometer sensor data. Laser (Optech Sentinel, Model 3100DV) and radar (Terra, Model TRA350/TRI40) altimeters mounted on fixtures attached to the rear hardpoint of the helicopter provide two independent altitude measurements to the DAQ computer. The dual altimeters were deployed to provide complementary information when operating over water or vegetation.

Figure 2. The Navigation Guidance Display Is Mounted on the Starboard Side of the Cockpit for the Pilot's Use During Surveys.

The helicopter pilot flies the survey using an onboard navigation guidance display developed specifically for this application. The sunlight-readable screen is mounted to the right of the instrument panel, as shown in Figure 2, so it is in the field of view of the pilot without reducing his ability to visualize the whole forward boom and the field immediately ahead of the helicopter. The survey parameters are set up in the pilot display computer. This computer shares the navigation and altimeter data with the DAQ computer.

The navigation guidance display provides a left-right indicator, an altitude display, an automatic line number increment, an adjustment for lateral offset, and a color-coded flight swath overlay, with the ability to zoom the presentation scale in or out on the display. The survey course over ground (COG) is plotted for the pilot in real time on the display, as are presentations showing the laser altimeter data and the GPS navigation fix quality.

2.2 PROCESS DESCRIPTION

2.2.1 Personnel Training

Shakedown exercises were an integral part of preparing for demonstrations. Once the airborne demonstrations began at the BBR, they took place almost flawlessly. This is in contrast to our experience during the shakedown surveys. There were three shakedown exercises at the Airfield separated by 1-month periods, each dominated by equipment breakdowns, malfunctions, and misadventures. We recovered and fixed most of the mistakes resulting from each exercise before the next shakedown. These shakedown exercises were critical to the success of the final demonstrations. It was important that they be separated by at least a month to enable us to evaluate problems, order parts, implement fixes, and plan for the following test.
For the BBR, APG, and Isleta demonstrations, pilot orientation flights were made prior to each demonstration. The pilot was requested to fly at the lowest altitude consistent with flight safety.

2.2.2 Data Processing

Survey and navigation data recorded in the DAQ computer are transferred (using a Zip disk, a "memory stick," or a notebook computer) to the DAS computer. The DAS software was developed specifically for the MTADS (vehicular, man-portable, and Airborne) as a standalone suite of programs, written using Interactive Data Language (IDL) development tools, and graphical user interfaces (GUI) working in a UNIX-based workstation environment. Over a period of about 2 years, the MTADS DAS was adapted to operate in a Windows™ environment on a PC.

The first task of the analyst is inspection and processing of the data in preparation for target analysis. Initially, files are reviewed to determine sensor data quality. Necessary edits are carried out to remove spurious sensor readings to clean up the navigation files. The background readings for all the sensors in the array are leveled to null sensor offsets. Glitches in the GPS navigation are corrected using the COG displays. Small offsets often occur when the mix of satellites used in the solution changes. Typically, a 1,000-point, down-the-track demedian filter is applied to correct for directional and platform-induced errors and for large-scale geological interferences. The navigation and sensor files are then processed together to establish a three-dimensional (3-D) coordinate location for each magnetometer sensor reading. Finally, the individual survey files are assembled into site survey maps (mapped data files). At this point, target analysis can begin. Historically, these operations have been carried out using utilities associated with the MTADS DAS. A working screen of the DAS is shown in Figure 3.

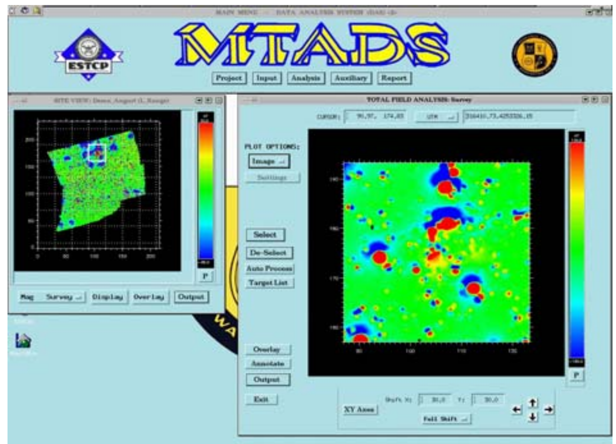

Figure 3. Working Screen of the MTADS DAS Showing the Survey Project View on the Left and an Expanded Analysis Window on the Right.

The DAS employs resident physics-based models to determine target size, position, and depth. Extensive data sets have been acquired and processed to calibrate the models. Using these models, we have demonstrated target location accuracies of ≈ 15 cm with the magnetometer system.

Although we have achieved impressive results using the DAS, it has proven difficult to transition the analysis utility to the general UXO user community. After the BBR demonstration, we began performing the data processing functions by generating mapped data files using a commercial software utility, Geosoft's Oasis montaj™.

2.2.3 Data Analysis

Currently, we create mapped data files using either Oasis montaj™ or the MTADS DAS. For target selection and analysis, we currently use the MTADS DAS. Under a separate program, we are in the process of converting the analysis routines developed under ESTCP and SERDP sponsorship to Geosoft Executables (GX), executable files that can be called from the Oasis environment. Ultimately, this will enable the analyst to perform all of the data analysis entirely within the Oasis environment. All target analyses reported in this document were accomplished using the MTADS DAS.

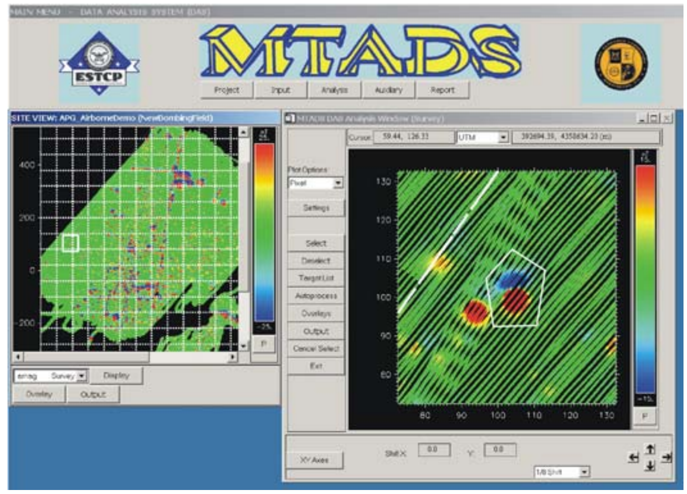

Figure 4. Site View and Data Analysis Screens from the MTADS Data Analysis Program. (A part of the Mine, Grenade, and Direct-Fire Weapons Range survey is shown on the left. An individual target is boxed for analysis on the right.)

The MTADS target analysis GUI is written at multiple levels to accommodate both sophisticated and novice users. A novice user can perform data analysis using menu-driven tools and the background default analysis settings (see Figure 4). When a magnetic anomaly, such as the one shown in Figure 4, is boxed for analysis using the computer mouse, the DAS selects the sensor data within the boxed area for consideration. Each sensor reading, with its HAE, is an input datum used in the seven-parameter iterative calculation to produce the best fit to a dipole model of the anomaly signature. Extensive training data sets (using inert ordnance) have been used to refine the algorithms to improve target analysis. In addition to position, depth, and size solutions, magnetic analyses provide dipole orientation and effective target-caliber information and, using a "goodness of fit" analysis, provide guidance in the target-fitting process.

2.3 PREVIOUS TESTING OF THE TECHNOLOGY

The Airborne MTADS system was extensively tested and improved as the result of the three shakedown tests conducted at the Aberdeen Proving Ground Airfield. For further information, see "Airborne MTADS Demonstration on the Impact Area of the Badlands Bombing Range: Technology Demonstration Plan".[18]

2.4 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Unlike the vehicular magnetometer system, the airborne system is not capable of detecting the smallest classes of buried UXO at depth. While the magnetic anomaly signals are spatially spread and diminished in intensity with the sensors farther above the ground, our modeling results indicated that, at an altitude of 2 m above the ground, the system should be capable of detecting bomb unit dispensed (BDU)-33s or Mk 82s in all geologies and ordnance targets equivalent to or larger than 2.75-in warheads in geologically quiet areas. This has generally been

borne out by the demonstrations described in this report. At the geologically quiet and topologically flat prove-out site at the Airfield, we efficiently detected both 60-mm and 81-mm mortars.[16,22] At the much more highly cluttered and geologically active Isleta range, in areas with rough ground surface or significant vegetation, we failed to detect several 105-mm projectiles.[17,23]

The extent to which spreading target signatures interfere with each other and are obscured by geological features was carefully evaluated in the first airborne demonstration at the BBR.[15] In that study, with fairly large UXO targets (105-mm to 8-in projectiles) relatively sparsely distributed on the site, detection efficiency for individual UXO was equivalent for the airborne and vehicular towed arrays. Because of the lower data density and the more widely spread anomaly signatures, it proved more difficult to discriminate between UXO and clutter signatures from the airborne data than from the vehicular data. At some APG sites,[16] significantly more targets would have to be dug behind an airborne survey than behind a corresponding vehicular survey. This is necessitated by the much higher target densities and the more complex mix of UXO threats on some of these ranges that result in merging and overlapping of adjacent target signatures. The cost tradeoffs between digging more targets and reduced survey production costs are (and will always be) site specific, depending on the types of UXO challenges, the relative density of targets, geological and topological conditions, and the size of the survey site.

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3.0 BADLANDS BOMBING RANGE DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

The objectives of this demonstration are enumerated below:

- Prepare a 10-acre area seeded with 25 ordnance items whose locations are unknown to the survey team. Survey the seeded area and an additional 100 acres with the vehicular MTADS magnetometer array.
- Complete an extended site survey that includes the seeded area, the additional 100-acre prove-out area, and other accessible parts of the impact area (IA) using the Airborne MTADS. (The airborne survey was planned to cover about 1,700 of the 2,400-acre IA.)
- Based on on-site target analysis of the data, use a UXO-certified recovery team to dig all targets on the survey dig list from the seeded area and the 100-acre survey area.
- Based on the dig list prepared from the airborne survey of the remaining area, dig targets from the area surveyed <u>only</u> by the airborne system, beginning with the highest priority and continuing until funds are exhausted.
- Provide the survey products and reports to the BBR Project Office of the Oglala Sioux Tribe (OST).
- Prepare a report[15] of our activities, which includes a description of all dug targets, a listing of the positions and descriptions of all targets observed in the survey that were not dug, and an evaluation of the airborne system's performance.

3.2 PERFORMANCE METRICS

3.2.1 Target Location Accuracy

A 10-acre area was seeded with 25 ordnance items, and the ground truth for the site was held by the U.S. Army Engineer Research and Development Center (ERDC) until after the magnetometry analyses from both the vehicular and airborne surveys had been submitted to ESTCP and ERDC. Comparisons between the systems were made, as well as evaluations of the absolute target location accuracies.

3.2.2 System Operational Performance

Field logs, kept for all survey activities, provided information about setup times, survey times, production rates, and equipment performance. In preparing for each day's operations, specific attention was given to the GPS satellite availability schedule. Field notes were made about the operational performance of the Airborne MTADS, specifically documenting special weather conditions or areas of difficult topography or vegetation that either influenced system performance or forced missed areas that could not be recovered by reflying.

The electronic data files provided additional information about field survey performance by documenting survey data collection times, the course used in data collection, stoppages during

data collection, how turnarounds were accomplished, and how well pilots lined up to begin their survey paths.

3.2.3 Detection Capability

This demonstration was the first use of the Airborne MTADS to conduct an extensive survey. We compared the relative abilities of the vehicular and the airborne systems to detect the seeded ordnance and to differentiate between clutter and ordnance. On the IA, the Airborne MTADS hardware performed flawlessly in the field, and the data processing, analysis, and target picking performance was routine, exceeding our expected production rates.

3.3 SITE SELECTION

MTADS demonstration projects during the period 1996-2001 were sponsored primarily by ESTCP and the U.S. Army Corps of Engineers, Huntsville Engineering and Support Center[3,4] (CEHNC). With the exception of a study of UXO contamination on the beach at the former Fort Pierce Naval Amphibious Training Base,[3] the MTADS demonstrations have focused on ranges impacted by bombing and aerial and ground gunnery training. In 1999, we conducted a vehicular MTADS survey of a small portion of the IA at the BBR.[17] In preparation for that project, NRL conducted site visits and archival records searches, coordinated OST activities, acquired aerial photography, and established first-order control points to support the survey. The 1999 survey also supported this and subsequent demonstrations.

In September 2001, we returned to the same range to complete the Advanced UXO Classification Demonstration with the vehicular MTADS (a different ESTCP project) and to conduct the first demonstration of the Airborne MTADS adjunct platform. In support of both of these ESTCP project demonstrations, a 10-acre site was seeded with 25 degaussed targets—five 8-in, ten 155-mm, and ten 105-mm projectiles. See Figure 5. This area was surveyed with the vehicular MTADS EM array. Subsequently, this site and an additional 100 acres were surveyed with the vehicular MTADS magnetometer array prior to beginning the Airborne MTADS survey.

3.4 TEST SITE HISTORY AND CHARACTERISTICS

In 1942, the Department of War annexed 341,725 acres of the Pine Ridge Reservation for use as an aerial gunnery and bombing range. This site is located in southwestern South Dakota, with the largest part of the Badlands Bombing Range located in Shannon County. From 1942 until 1948, various sections of this range were used for bombing exercises and air-to-ground operations. Since 1960, portions of the land have been returned to the OST in a stepwise fashion. In 1968, Congress enacted Public Law 90-468, returning 202,357 acres to the OST and setting aside 136,882 acres of formerly held OST lands to form the Badlands National Monument, to be managed by the National Park Service. In 1978, all remaining BBR lands were declared excess federal property with the exception of 2,486 acres (subsequently referred to as the Air Force Retained Area or the Impact Area). Circa 1965, the South Dakota National Guard placed as many as 100 car bodies on the 2,486-acre area and began using them as ground-to-ground artillery targets during training exercises. The National Guard training exercises took place on the IA between 1966 and 1973.

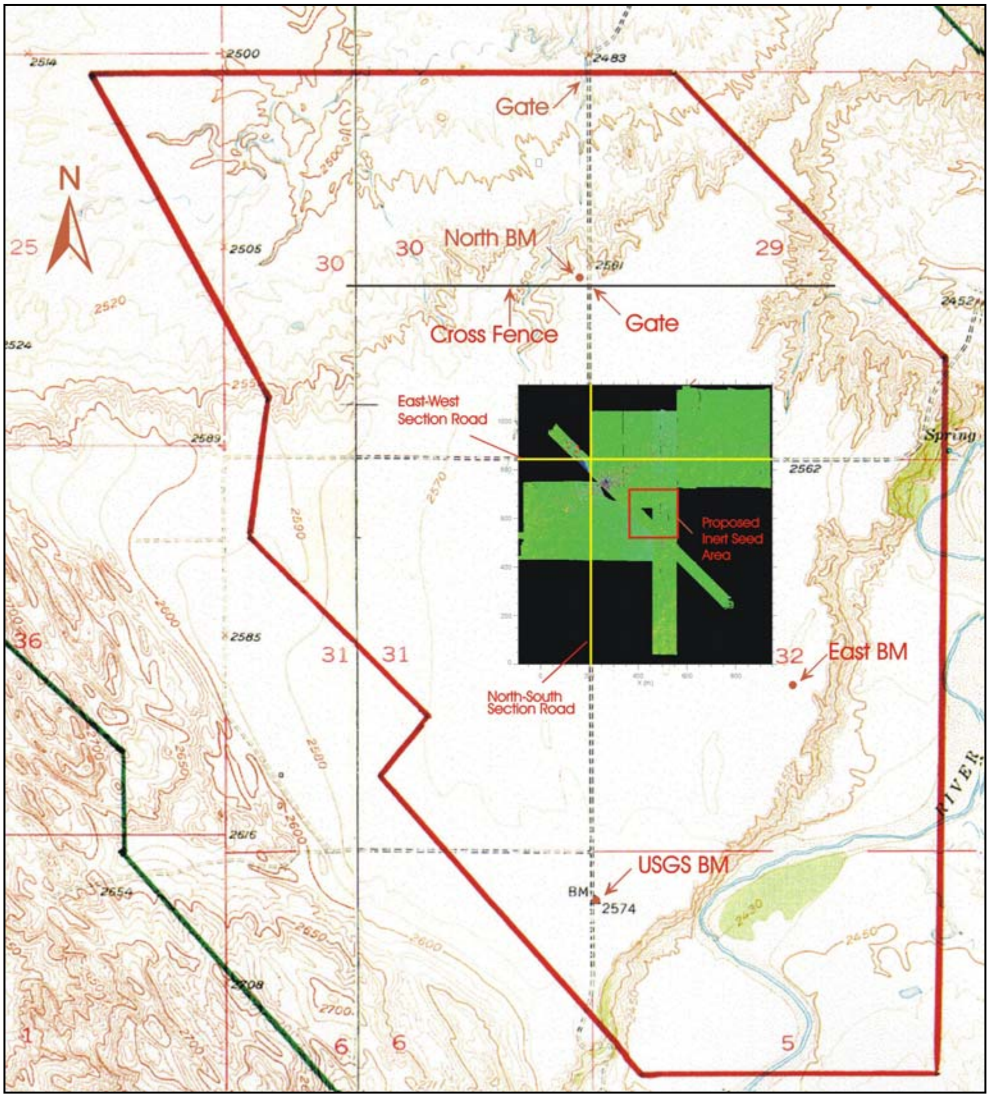

Figure 5. The BBR Impact Area (within the red boundary)**, the 1999 Survey Area** (shown in green)**, and the 2001 10-Acre Seed Target Area** (bounded by a thinner red border) **Within This Area.**

There have been six UXO clearance operations carried out on the BBR between 1948 and 1997. These are discussed in more detail in Reference 28. Only two, in 1975 and 1996, have significant relevance to the present demonstration on the IA. No record of air-to-ground exercises exists that specifies the IA as a target. During the summer and fall of 1975, 10 Explosive Ordnance Detection (EOD) personnel participated in a walking search line clearance of 22,403 acres and a vehicular search of 19,222 acres. This included a walking search line survey of the entire IA and the buffer zone. With the exception of the IA, all lands were declared as cleared and certified for return to the OST. The IA reportedly contained too much ordnance and explosive (OE) material to declare the area cleared.

During the 4-month summer period in 1996, a walking and driving search line ordnance clearance was conducted by 20 EOD personnel from Ellsworth Air Force Base (AFB). With the

exception of 56 acres of rugged terrain along the White River escarpment, the entire IA was covered. EOD teams used metal detectors to clear the area to a depth of 1.5 ft. The OE scrap recovered included 4,000 lbs of shrapnel (pieces larger than 3 in) and an additional 8,000 lbs of non-ordnance-related metal scrap.

3.5 PHYSICAL SETUP AND OPERATIONS

Support for the MTADS demonstration on the IA was provided by the ESTCP. Oversight of the NRL activities on the IA was provided by the Environmental Office (Civ 28 CES/CEVR) of Ellsworth AFB. All operations were coordinated with the ESTCP Program Office, Corps of Engineers Northwestern Division Omaha District (CENWO), Ellsworth AFB, EPA (Region 8), the South Dakota Department of Environment and Natural Resources, and the Badlands Bombing Range Project Office of the OST. The specific operations are described in the demonstration test plan.[18]

NRL, Code 6110, was the manager for all activities associated with the Airborne MTADS demonstration on the IA. The NRL on-site project manager, Dr. J.R. McDonald, was responsible for coordinating operations at the IA and approving alterations or changes to the demonstration plan or schedule. All persons working on site were NRL employees, contractors working for NRL, or employees or subcontractors of the prime contractors.

3.5.1 The Seed Target Area

APG degaussed inert ordnance to prepare the seed target area. The ordnance was shipped to ERDC in Vicksburg, Mississippi, and was transported from there to the IA in South Dakota where the 10-acre seeded site was prepared during August 2001. NRL defined the corners of the test site and provided the coordinates to ERDC. The boundary of the 10-acre (200 m × 200 m) area is indicated by the thinner red outline in Figure 5. The 10 acres fall primarily in an area that was surveyed in 1999 using the vehicular magnetometer array and was subsequently remediated to remove targets that were potentially 105-mm, 155-mm, or 8-in projectiles. Because the area is only 100-300 m away from the bull's eye, there is a relatively high density of shrapnel and clutter present on the site. The ground truth for the site (Table 2) was held by ERDC until after the magnetometry analyses from both the vehicular and airborne surveys had been submitted to ESTCP and ERDC.

3.5.2 Logistics

Because of the complexity caused by the simultaneous parallel airborne demonstration and the Advanced UXO Classification Demonstration, it was important that the logistics support be carefully planned and coordinated. The logistics facilities served as a focal point for all field activities.

Figure 6 shows some of the logistics support equipment that was set up for the demonstration. The leftmost trailer served as the command center. All data analysis computers were housed there. The next trailer provided storage for the hardware and housed all the battery-charging stations. The third trailer was the site office for the OST workers and, during the excavation operations, also for the UXO teams. The fourth trailer, which opened at both ends, served as a

drive-through garage for the vehicular systems. Between the fourth trailer and the tractor-trailer, a tent cover was set up to provide protection for working on the vehicles or other equipment. The tractor-trailer was used to transport the vehicular equipment and the airborne sensor platform to the site. The truck at the south end was the Jet A tanker for the helicopter. To the east of this equipment were located portable toilets, a 65 kW generator, and a diesel storage tank. Not shown in the image are the two four-wheel-drive backhoes that supported the UXO excavation work.

Table 2. Ground Truth Table for the Inert Seed Ordnance Emplaced at the Impact Area.

Item #	Northing (m)	Easting (m)	Depth (m)	Azi. (deg)	Incl. (deg)	Nose U/D	Serial No.
8-inch							
1-2	4838171.34	722824.74	0.75	350	75	D	4
1-4	4838142.67	722957.56	0.50	270	45	D	5
1-6	4838117.82	722874.46	0.75	40	80	D	3
1-8	4838082.55	722834.30	0.30	10	0	H	6
1-10	4838019.39	722889.76	0.50	340	40	D	2
155-mm							
1-12	4838120.88	722786.50	0.85	0	45	D	10
1-14	4838086.48	722802.76	0.25	250	65	D	8
1-16	4838176.31	722813.27	0.60	15	80	D	12
1-18	4838143.69	722819.03	0.85	115	45	D	11
1-20	4838066.32	722848.56	0.25	165	70	D	13
1-22	4838142.69	722860.13	0.25	110	0	H	15
1-24	4838168.67	722886.90	0.30	360	35	D	9
1-26	4838106.46	722901.24	0.55	75	45	U	14
1-28	4838202.03	722921.32	0.60	30	40	D	6
1-30	4838137.07	722919.42	0.40	310	55	D	7
105-mm							
1-32	4838196.19	722853.42	0.25	110	35	D	16
1-34	4838176.23	722831.42	0.92	05	75	D	9
1-36	4838174.21	722879.23	0.40	115	45	D	10
1-38	4838164.65	722931.82	0.25	30	0	H	7
1-40	4838141.72	722893.58	0.50	50	55	D	13
1-42	4838118.78	722830.47	0.60	245	75	U	15
1-44	4838070.04	722926.09	0.50	65	60	D	12
1-46	4838064.41	722957.64	0.25	315	80	D	11
1-48	4838050.93	722914.61	0.30	25	35	D	8
1-50	4838032.77	722808.48	0.30	360	45	D	14

U - up
D - down
H - horizontal

3.5.3 On-Site Support

Two NRL employees were on site at all times during operations. Dr. J.R. McDonald was the principal investigator (PI) and on-site manager for the Airborne Demonstration Project. Dr. H.H. Nelson was the PI and on-site manager for the Advanced UXO Classification Demonstration. Nova Research, Inc., coordinated all rentals and leases for on-site equipment. The site safety officer was an EOD-certified Nova employee who also had responsibility for site hardware maintenance and vehicle operation. AETC Incorporated supported the demonstrations with five on-site employees. They supported the data collection and processing for both projects.

Additionally, they supported the Advanced UXO Classification Demonstration's field activities, managed flight operations for the airborne survey, performed data analysis, and created survey products. Helicopter Transport Services, Inc., provided the helicopter and pilot for the airborne survey.

Vehicular survey operations were supported by three to five OST members from the BBR Project Office. Additionally, two EOD technicians from the BBR Project Office supported the dig teams. All target way pointing and recovery operations were the responsibility of Explosive Ordnance Technology, Inc. (EOTI). The four-person EOTI staff and the certified OST technicians formed two dig teams. These teams conducted all target recovery operations, recorded the results of each dig on the dig sheets, photographed the recovered objects from each hole, and refilled and tamped each hole, returning it to grade. EOTI was responsible for providing explosives and blowing in place all recovered ordnance. All recovered OE scrap (and other metal scrap) was certified as explosives-free and stockpiled for disposal by Ellsworth AFB.

Figure 6. Logistics Setup Supporting the Demonstrations at the Impact Area.

3.5.4 Demonstration Activity

The spare assemblies for the airborne platform were shipped by motor freight for storage at the Rapid City Regional Airport. Since they were not needed, they remained unopened and were returned to NRL. All the other equipment was shipped in a 53-ft tractor trailer that left Blossom Point on August 31 for the IA. A Nova employee arrived at the IA the week of September 3 to oversee the placement of the logistics support rental equipment. The activity log in Table 3 describes field activities of each of the project demonstrations. The equipment difficulties with the EM sensors required adjusting the schedules for the vehicular survey operations to allow for repairs and recalibration of the EM array.

The September 11 terrorist attacks in New York and Washington delayed for 1 week the departure of the helicopter from Baltimore to support our operations. It was uncertain until September 20 whether or not we would be able to conduct any airborne survey activities.

Table 3. Activity Log for the Demonstration Projects on the IA.

Date	Activity	Result	Comment
5 Sep	Logistics support	All components in place	Electrical wiring complete
6 Sep	Trailer truck arrives on site		Backhoe used to repair road
7 Sep	MTADS components unpacked and assembled		
9 Sep	NRL and support contractors arrive		
10 Sep	Coordinate OST and contractor activities	Set up data analysis trailer and prepare for EM vehicular survey	EM 61 Mk II calibration tests, hardware failure, equipment shipped to Canada for repair
11, 12 Sep	Begin vehicle mag survey of South and Seed Target Areas	Survey 200 X 600 m area, including the seed target area	11 data files, 9.6 survey hours
12-14 Sep	Begin vehicle mag survey of north area	Survey 325 X 400 m area	13 data files, 10.0 survey hours
14, 15 Sep	Begin vehicle mag survey of west area	Survey 525 X 325 m area	14 data files, 11.3 survey hours
17 Sep	Vehicle mag survey analysis, South, seed, North, and West areas	Completed target analysis and prepared spreadsheets	
17 Sep	Deploy EM61 Mk I	Center sensor failed calibration	Shipped sensor to Canada for repair
18 Sep	Deploy EM61 Mk I on Seed Target Area	Survey without center sensor	3 data files, 1.61 survey hours
19 Sep	Deploy EM61 Mk II following repairs		Perform calibration tests
20 Sep	Deploy EM61 Mk II on Seed Target Area	Complete N/S survey	11 data files, 6.3 survey hours, repaired EM61, Mk I received
21 Sep	Deploy EM61 Mk II on Seed Target Area	Complete E/W survey	14 data files, 6.8 survey hours
22 Sep	Deploy EM61 Mk I on Seed Target Area	Complete E/W survey	8 data files, 6.0 survey hours
22 Sep	Assemble airborne components		Helo arrives on site
23 Sep	Deploy EM61 Mk I on Seed Target Area	Complete N/S Survey	8 data files, 7.0 survey hours
23 Sep	Install platform on helo	Conduct practice survey of North area	1 data file, 1.1 survey hours, GPS data defective
23 Sep	Airborne survey of South and seed areas		1 data file, 0.9 survey hour
24 Sep	Deploy EM61 Mk I on Seed Target Area containing 60- and 81-mm	Survey 50 X 200 m area, complete E/W survey	3 data files, 1.61 survey hours
24 Sep	Airborne platform repairs	Replace GPS antennas and mag sensor 5 and cables	
25 Sep	Airborne surveys, Airborne South sorties	Sortie South 12 Sortie South 1 Sortie South 0 Sortie South 11 Sortie South 5 Sortie South 6	16 acres, 0.4 survey hours, 107 acres, 1.5 survey hours, 107 acres, 2.0 survey hours, 26 acres, 0.5 survey hours, 88 acres, 1.1 survey hours, 78 acres, 0.9 survey hours, 68 acres, 0.9 survey hours, 34 acres, 0.6 survey hours
25 Sep	Analysis of Airborne South/seed data	Completed joint target analysis of South seed area	Submitted seed dig lists to ESTCP and ERDC

Table 3. Activity Log for the Demonstration Projects on the IA. (continued)

Date	Activity	Result	Comment
26 Sep	Airborne surveys, Airborne South and North sorties	Sortie South 8, Sortie South 9 (data lost), Sortie South 10 Sortie South 13 Sortie South 10, reflight Sortie North 1	23 acres, 0.4 survey hour 47 acres, 0.7 survey hour 37 acres, 0.6 survey hour 5 acres, 0.1 survey hour 37 acres, 0.7 survey hour 93 acres, 1.3 survey hours 87 acres, 1.5 survey hours 91 acres, 1.2 survey hours 47 acres, 0.7 survey hour
27 Sep	Airborne surveys, reflights, and calibrations	South, missed area reflights Sortie North 8 Sortie North 4 Sortie North 5, Upper Plateau Sortie North 6 Sortie North 5, Lower Plateau Sortie North	0.5 survey hour 103 acres, 1.5 survey hours 96 acres, 1.2 survey hours 44 acres, 0.5 survey hour 100 acres, 1.2 survey hours 55 acres, 0.7 survey hour 102 acres, 1.0 survey hour 0.3 hour
27, 28 Sep	Unmount airborne platform	Helo departs	
28 Sep	Dig teams arrive on site	Coordinate with tribal team and analysis teams	Practice target waypointing
28 Sep	Airborne target analysis	Analysis completed and reconciled	Airborne spreadsheets and dig lists prepared
1 Oct	Dig teams waypoint South and seed areas	Begin recovering seed targets	
? Oct	Target recovery from ground surveys	All targets dug in vehicle surveyed areas	Began digging airborne targets
19–23 Nov	Airborne target digging terminated	Final blow-in-place demolition, OE scrap sorted and certified	
23 Nov	Site cleaned, flags removed	Dig teams depart	
30 Nov	All logistics support removed		

4.0 BADLANDS BOMBING RANGE PERFORMANCE ASSESSMENT

4.1 PERFORMANCE DATA

4.1.1 Overview

Initially, the vehicular and airborne surveys of the Seed Target Area, shown in Figure 7, were performed. We compared the relative abilities of the two systems to detect the seeded ordnance and to differentiate between clutter and ordnance. Following the surveys of the Seed Target Area, a 100-acre area was jointly surveyed by the airborne and vehicular systems. In Figure 7, the 100-acre joint vehicular and airborne surveys are shown as three separate survey areas: the North, South, and West survey blocks.

The remaining areas surveyed by the airborne system were collectively referred to as the Airborne Production Survey area. The overall performance of the airborne survey system was then evaluated and compared with the probable results that would have resulted from an independent vehicular survey.

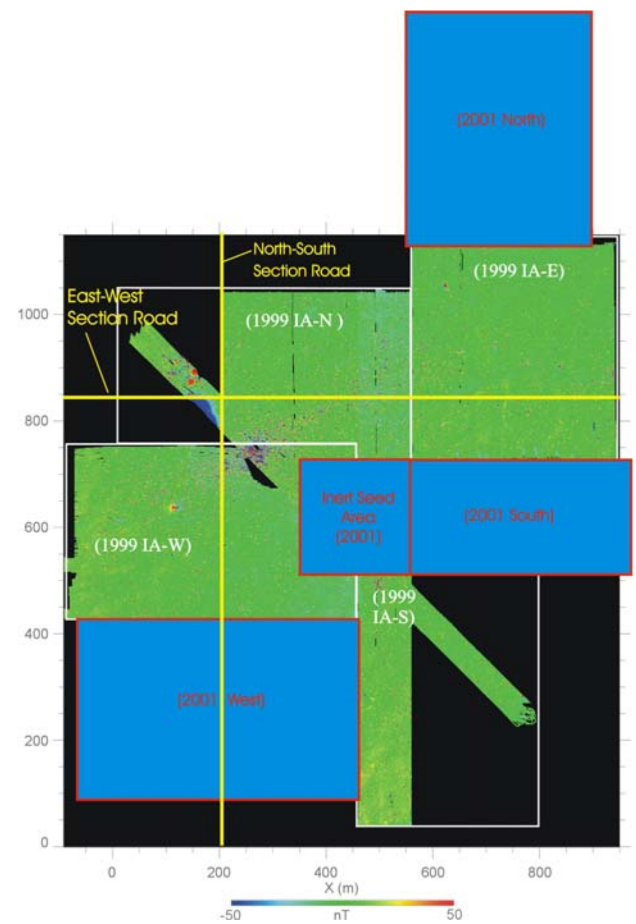

Figure 7. Magnetic Anomaly Map of the Areas Surveyed in 1999. (The vehicular survey areas covered in the 2001 demonstration are shown in blue.)

Figure 7 provides a perspective of the vehicular surveys conducted during this demonstration compared to the vehicular surveys conducted in the 1999 demonstration. The areas surveyed with the vehicular system in the 2001 demonstration are overlaid in blue showing their relationship to the earlier surveys.

The 2001 vehicular surveys were partitioned into three separate areas denoted as 2001 West, 2001 North, and 2001 South. The 2001 South block is contiguous to the 10-acre Seed Target Area. The Seed Target Area was extended in this way to create the Seed-South survey block because the longer East-West lanes were more efficient to survey with both the vehicular and the airborne systems. The Seed Target Area lies 100–300 m SE from the center of the bull's eye and is therefore fairly densely populated with shrapnel and clutter left behind following the 1999 remediation. The remaining 20 acres that constitute the 2001 South survey block lie in an area that had not been previously surveyed by the MTADS. The 2001 Seed-South block was independently surveyed using the Airborne MTADS (Table 4) to provide an initial data set for comparative analysis with the vehicular data. The area was reflown as part of sortie South 3 (see Section 3.6.5 and Figure 19 in the final

report); however, the data used for target analysis of the 2001 Seed-South block was from the initial mission.

Table 4. Summary of the Target Reports for All the Vehicular and Airborne Target Analyses for the North, West, and South blocks and the Seed Target Area.

Survey Area		Priority 1	Priority 2	Priority 3	Priority 4	Priority 5	Priority 6	Total
Seed Target Area	Vehicular mag	24	15	36	3	37	55	170
	Airborne mag analysis	36	34	69	14	8	24	185
	V-mag targets not in airborne analysis	-	-	-	-	-	-	25
South Survey	Vehicular mag	6	13	25	8	17	1	70
	Airborne Mag Analysis	5	57	80	3	6	3	154
	V-mag targets not in airborne analysis	-	-	-	-	-	-	17
West Survey	Vehicular mag	13	17	45	18	43	43	179
	Airborne mag analysis	43	134	129	11	23	13	353
	V-mag targets not in airborne analysis	-	-	-	-	-	-	19
North Survey	Vehicular mag	2	10	11	8	10	11	52
	Airborne mag analysis	16	29	24	5	12	9	95
	V-mag targets not in airborne analysis	-	-	-	-	-	-	8
Combined Totals	Vehicular mag	45	55	117	37	107	110	471
	Airborne mag analysis	101	255	303	33	49	49	790
	V-mag targets not in airborne analysis	-	-	-	-	-	-	69

4.1.2 The Seed Target Surveys

The Seed Target Area is pictorially defined in Figure 7. Figure 8 shows magnetic anomaly images of the Seed Target Area from the vehicular and airborne surveys. Many of the inert ordnance targets are apparent. The coordinate system in these images (and all other anomaly images generated by the MTADS DAS) is a user-defined local coordinate system in meters. The origin of the local coordinate system was chosen to be identical to that used in the 1999 MTADS survey. The offset between local and Universal Transverse Mercator (UTM) coordinates was recorded at the top of all target analysis spreadsheets.

The vehicular analysis was performed first. The airborne analysis was carried out with both the vehicular and airborne data displayed side by side, as shown in Figure 9. In the Seed Target Area, the airborne target picks have the same target numbers as in the vehicular survey analysis. All inert buried ordnance was detected and analyzed in both the vehicular and airborne surveys.

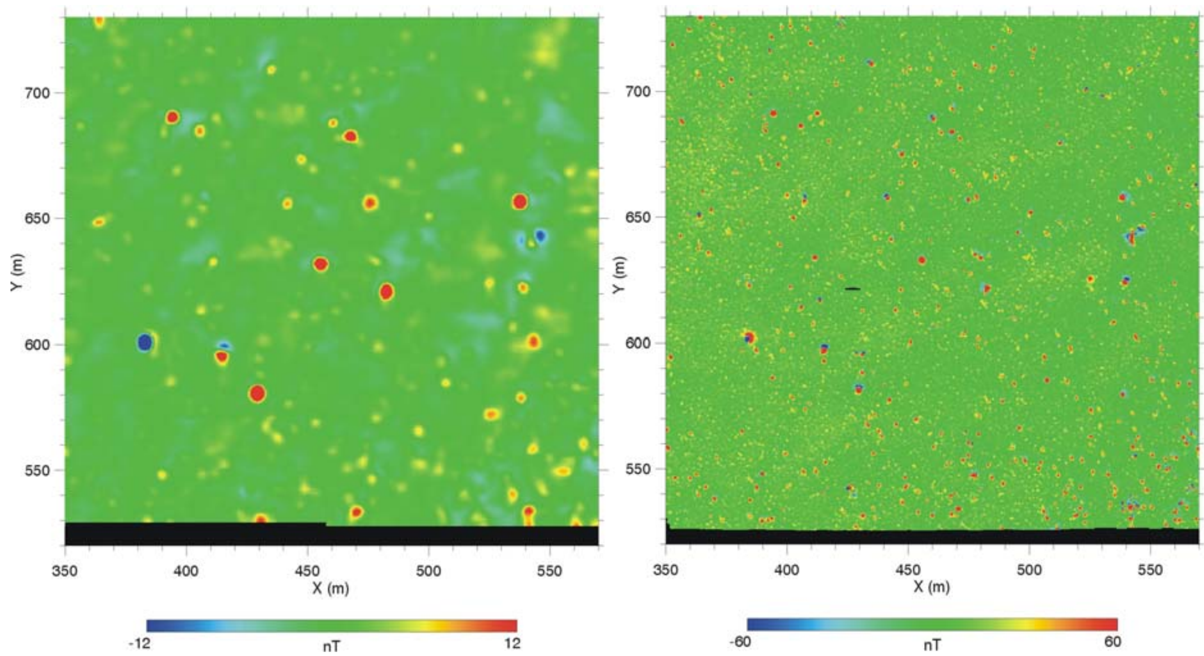

Figure 8. Magnetic Anomaly Images of the Seed Target Area from the Airborne Survey (left) **and the Vehicular Survey** (right)**.** (The Seed Target Area is 200 m × 200 m; the southwest corner coordinates are X = 360 m, Y = 530 m.)

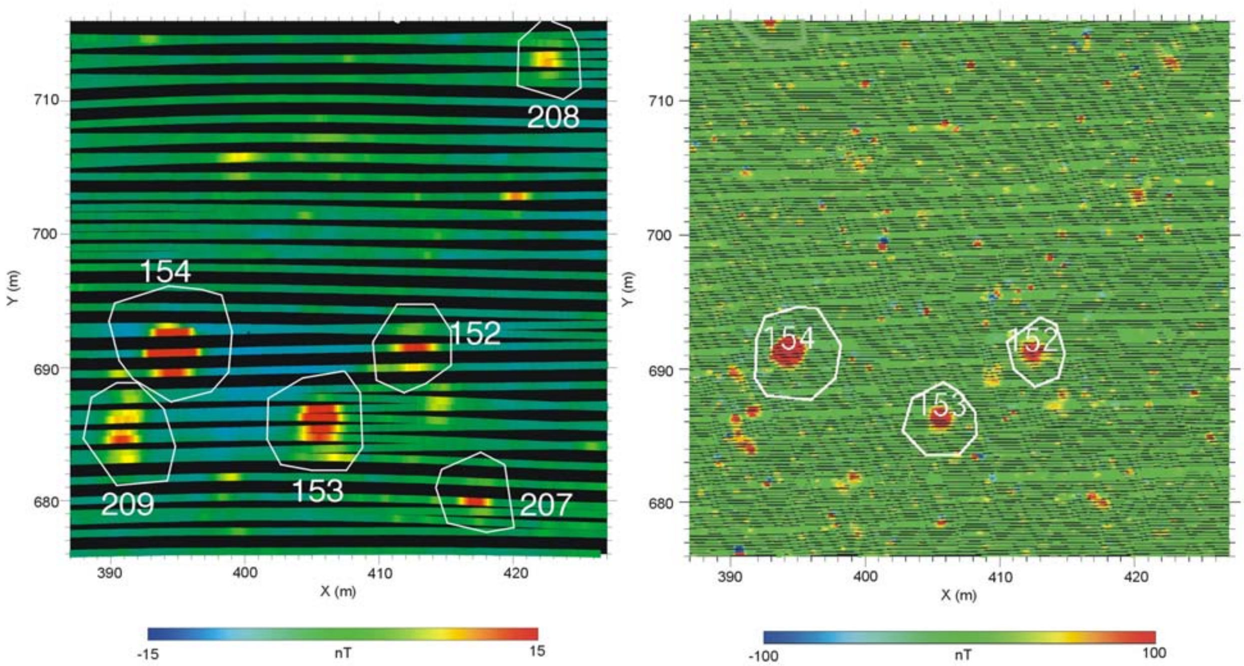

Figure 9. Magnetic Anomaly Maps of a Portion of the Seed Target Area Presented in Pixel Format. (The airborne survey is shown on the left and the vehicular survey on the right.)

4.1.3 The South, West, and North Surveys

4.1.3.1 The South, West, and North Vehicular Surveys

Figure 7 shows the relative positions of the 2001 vehicular magnetometer survey areas. Excluding the Seed Target Area, the remainder of the vehicular magnetometer survey encompasses 99.6 acres (40.3 hectares). The vehicular data were analyzed immediately on site in preparation for the anticipated onslaught of airborne data once the Airborne Production Survey began. The data were processed on the six-category priority scale.

4.1.3.2 The South, West, and North Airborne Surveys

The Seed Target Area and the South block were initially flown on September 23 as a single, continuous 200 m × 600 m mission in the first airborne test survey at the IA. Data from this initial 30-acre survey were used to carry out the airborne target analysis of the Seed Target Area and South block.

Target digging in the Seed Target Area was based on the combined analyses of the vehicular magnetometer and EM and airborne magnetometer MTADS survey data. Every target appearing in any of the dig lists was dug. Digging in the South, West, and North blocks was based on only the target list prepared from the vehicular magnetometer array survey. The airborne data were analyzed retrospectively for the South, West, and North blocks because, during the last week in September, airborne data for areas of the IA not covered in the 1999 survey or in the 2001 vehicular survey were being analyzed first in preparation for digging targets in these previously unsurveyed areas. The airborne and vehicular magnetometry data were jointly analyzed for the Seed Target Area, as described in Section 4.1.1 of this report and in greater detail in Section 3.6.1 of the final report, to develop rules for the airborne analysis. The airborne data overlapping the remaining 100 acres of the vehicular survey were analyzed semi-independently of the vehicular data. This means that the airborne target anomalies were independently chosen and analyzed using only the airborne data. However, the results were carefully scrutinized by comparing the joint data sets to evaluate the rules that were developed during the Seed Target Area joint analysis.

4.1.4 Comparative Performance of the Two Systems

Table 5 summarizes the results of the target recovery operations on these survey blocks and in the Seed Target Area. The values in parentheses refer to the airborne analyses. All inert and live UXO detected in the vehicular survey and analyses were also detected in the airborne survey. Interestingly, target 121 in the Seed Target Area that was incorrectly classified as category 6, OE scrap, by the vehicular survey and analysis was classified as a category 3 UXO target in the airborne survey and analysis. The clutter above the target, which confused the vehicular analysis, was not an interference in the airborne anomaly signal.

Table 5. Correlation of the Ordnance Recovery Data with the Analysis Assignments for the Seed Target Area and the North, West, and South Survey Blocks.

Survey Area			Category*						Total
			1	2	3	4	5	6	
Seed Target Area	Targets analyzed		24	15	36	3	37	55	170
	Targets excavated		24	15	36	3	37	55	170
	Inert UXO recovered	105-mm	7 (8)	3 (2)	-	-	-	-	10
		155-mm	7 (9)	2 (1)	-	-	-	1	10
		8-in	4 (4)	-	-	-	1 (1)	-	5
	Live UXO recovered	105-mm	-	-	-	-	-	-	-
		155-mm	-	-	(1)	-	-	1	1
		8-in	-	-	-	-	-	-	-
South Survey	Targets analyzed		6	13	25	8	17	1	70
	Targets excavated		6	13	25	8	17	1	70
	Live UXO recovered	105-mm	-	-	-	-	-	-	-
		155-mm	1 (1)	1 (1)	-	-	-	-	2
		8-in	2 (2)	-	-	-	-	-	2
West Survey	Targets analyzed		13	17	45	18	43	43	179
	Targets excavated		13	17	45	18	43	43	179
	Live UXO recovered	105-mm	-	-	-	-	-	-	
		155-mm	1 (2)	1	-	-	-	-	2
		8-in	(1)	-	1	-	-	-	1
North Survey	Targets analyzed		2	10	11	8	10	11	52
	Targets excavated		2	10	11	8	10	11	52
	Live UXO recovered	105-mm	-	-	-	-	-	-	-
		155-mm	1 (1)	-	-	-	-	-	1
		8-in	1 (1)	-	-	-	-		1
Combined Totals	Targets analyzed		45	55	117	37	107	110	471
	Targets excavated		45	55	117	37	107	110	471
	Live UXO recovered	105-mm	-	-	-	-	-	-	-
		155-mm	3 (4)	2 (1)	-	-	-	-	5
		8-in	3 (4)	-	1	-	-	-	4
	Total inerts		19(21)	5(3)	-	-	1(1)	-	25

* Values in parentheses refer to recoveries made from the airborne survey and analysis.

Table 4 contains a summary of all the vehicular and airborne target analyses comparing the performances of the two systems for all categories of targets. The most striking information in Table 4 is that the airborne survey analyses contain 67% more targets than the vehicular surveys. This is the result of the effects shown in Figures 8 and 9. The high-density data in the vehicular survey enables many non-UXO targets to be excluded from consideration on the basis of shape information that is not available in the much sparser airborne data. The airborne analyses also produce priority assignments that are skewed toward the priority 1, 2, and 3 categories, again because the shape information in the anomaly signature that the analyst uses is not present to the same degree in the airborne data. While we have demonstrated that the Impact Area can be effectively cleared of UXO using either the vehicular or the airborne survey approaches, the airborne survey necessarily requires more targets to be dug.

In the following discussion, we group the Seed Target Area with the other vehicular surveys and consider both inert ordnance and live UXO as ordnance. On this 110-acre area, of the 471 targets analyzed and dug, 217 targets had been classified as UXO and 254 as more likely not UXO. We recovered 35 intact ordnance targets. In the vehicular analysis, 24 ordnance were classified as category 1, seven as category 2, one as category 3, one as category 5, and one as

category 6. The category 5 target (an inert 155-mm projectile) was misclassified because it had been incorrectly degaussed. Target 121 (discussed earlier in this section) was also misclassified as category 6 in the vehicular survey analysis.

Based on the vehicular analysis, if one accepts a 97% (or a 94%) goal for the UXO cleanup process, the above analysis would support leaving 110 of the category 6 (or 217 of the categories 5 and 6) targets undug behind the vehicular MTADS survey. Leaving the 110 category 6 targets undug would leave one UXO in the field. Leaving the 217 categories 5 and 6 targets undug would leave two UXO in the field.

A final observation relating to the target analysis process should be made. On this 110-acre site, 471 anomalies appear in the target spreadsheets. On the basis of a signal-intensity threshold or object-analyzed size threshold, there are several hundred more objects in the area that would be included in the dig list. In our interactive analysis, these additional targets were excluded either by visual inspection of the anomaly signature or by trial fits of the anomalies. These additional objects would appear in the dig list if our automated target picker were the analyst or if a Mag and Flag team did the survey.

4.1.5 The Airborne Production Survey

Between September 24 and 27 (Table 6), all easily accessible areas of the IA were surveyed with the airborne system. The IA was surveyed in an east-west direction. The operation was divided into 22 missions, or sorties (see Figure 10). Over most of the area, survey lines were 2.5–3 km long; the longer sorties were designed to be completed in about an hour. Data from the North 1–3 and South 0–8 airborne (Figure 10) sorties were extracted to conduct separate airborne analyses of the vehicular West and North survey areas.

Table 6. Airborne MTADS Survey Production Rates. (Hours in parentheses are not included in survey calculations.)

Date	Flight Hours		Survey File Hours	Survey Acres
Sunday 9/23	Assembly Calibration/training	(2.4)	(2.0)	(66)
Monday 9/24	Survey	5.1	4.4	313
Tuesday 9/25	Survey	8.9	7.9	524
Wednesday 9/26	Survey	8.6	6.6	383
Thursday 9/27	Survey	7.5	7.0	465
	Ferry time	2.0		
Total		32.1	25.9	1685

Altogether, about 250 acres north of the cross fence were surveyed. Most of this area is 50–75 ft lower in elevation than the Bouquet Table and was not likely part of the original impact area, although overshoots could clearly have strayed into the area.

A coarse-scale magnetic anomaly image of the entire airborne survey area is shown in Figure 11. At this scale, the fence lines, geological features, the MTADS support trailers, and (in a few cases) individual buried targets are visible. The entire site was divided into five separate survey blocks because of its size and because two or three people were working on target analysis at the same time. Intermittently, the analysts reviewed each other's outputs to ensure consistency. On Friday September 28, the target analysis was completed and reviewed for consistency. On Saturday September 29, the target dig sheets were prepared from the spreadsheets, and the files were prepared for loading into the GPS way pointing equipment. A calibration way point target was set up and flagged east of the equipment trailer. This target appeared at the top of each list of targets to be acquired and flagged each day before work began in the field.

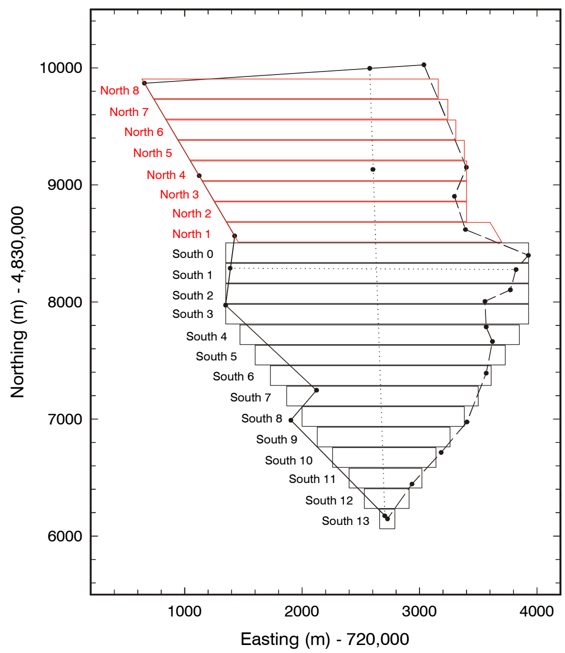

Figure 10. Layout for the Individual Sorties Flown by the Airborne MTADS Surveying the Impact Area.

The airborne targets in Table 7 were dug by analysis category. All 82 category 1 and 176 category 2 targets were dug. Only 270 of 486 category 3 targets were recovered; 216 category 3, and 449 category 4–6 targets remain undug. Two dig teams worked independently each team with two EOTI explosives-certified members and one OST explosives technician. Each team worked with hand tools and backhoes, depending on the size and depth of the individual target being prosecuted. All metallic objects associated with each flag were recovered and photographed, and the hole was cleared using a metal detector before closing.

4.2 PERFORMANCE CRITERIA

Performance evaluation criteria include system detection sensitivity, accuracy of location and depth predictions, and navigation system performance.

4.3 PERFORMANCE ASSESSMENT

Our program performance objective was to test the operation of the Airborne MTADS in a realistic survey against the performance of the vehicular system and against other competing technologies including Mag and Flag. The objective of the 1999 Mag and Flag clearance conducted by Air Force EOD teams was to flag targets larger than 3 in at depths less than 1.5 ft. Based on the 1999 clearance reports, the Mag and Flag clearance of this range did not effectively lead to the discovery or removal of the live high explosive (HE)-filled dud projectiles; only one live projectile was found in the 1999 clearance. Much of the IA is significantly contaminated with small metallic clutter, OE shrapnel, fencing material, and auto body parts. This problem is so pervasive that it effectively defeats the use of nonrecording sensors. Using the handheld sensors typically employed in Mag and Flag surveys, it is very difficult to differentiate target

size. Setting the sensor sensitivity to detect a 105-mm projectile at 1.5 ft will ensure that it rings off on a 2-in to 3-in piece of shrapnel near the surface. On much of this range, the correctly tuned sensor would constantly alarm, leading to thousands of flags per acre. It is not clear from the 1999 clearance reports whether the Mag and Flag sensors were calibrated against projectiles buried at the required detection limits.

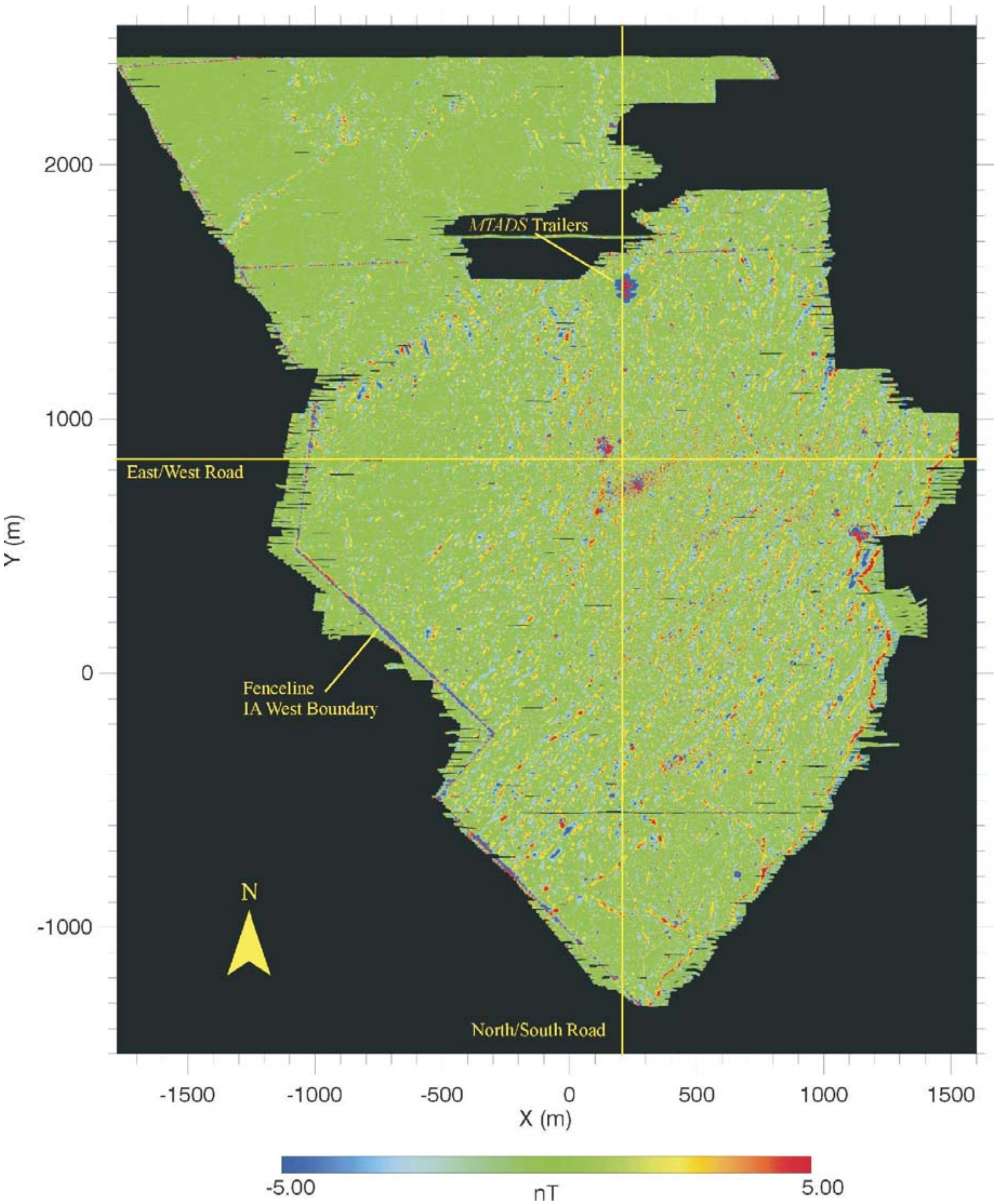

Figure 11. Magnetic Anomaly Image for the Airborne MTADS Survey of the Impact Area.

Table 7. Summary of the Target Analysis and Recovery Operations Following the Airborne Survey.

Survey Area		Category						Total
		1	2	3	4	5	6	
Targets Analyzed		82	176	486	208	155	86	1,193
Targets Excavated		82	176	270	-	-	-	528
Live UXO Recovered	105-mm	-	-	-	-	-	-	-
	155-mm	-	3	3	-	-	-	6
	8-in	-	2	2	-	-	-	4

The data collection approach used by the vehicular magnetometer MTADS is appropriate for making the classification decisions that enable confidently leaving ≈ 90% of the metallic scrap items in the field. The results of the 1999 MTADS survey demonstrated that this can be accomplished, and the analysis of the Seed Target Area in this demonstration verified it. The relatively high ratio of OE scrap recoveries to live projectile recoveries from the vehicular magnetometer survey was again driven by the curious fact that unintended postimpact detonations of the 155-mm and 8-in projectiles leave shrapnel cluster patterns that often cannot be distinguished from intact 105-mm projectiles.

4.3.1 Detection Sensitivity

The ability to detect targets depends primarily on the sensitivity of the sensors, the completeness of the survey coverage, and the signal-to-noise ratio in the survey data. The Airborne MTADS detection efficiency in the Seed Target Area and in the 100-acre common area survey for the 105-mm, 155-mm, and 8-in projectiles was indistinguishable from that of the vehicular survey. Each detected all the seed area UXO (inert and live) and detected the same UXO projectiles in the 100-acre common survey area. The airborne system can clearly be relied on to detect buried projectiles. It should also be noted that among the airborne target digs was a 2.75-in inert rocket warhead that had evidently wandered away from whatever its mission was supposed to be.

The lower density of the airborne data made classification decisions more difficult compared with the vehicular data. On the 110 acres surveyed by both systems, 60% more targets would have to be dug behind the airborne survey than behind the vehicular MTADS if all targets (category 1–6) were dug. The cost implications of this effect are discussed in Section 4.4.2, Cost Performance, and Section 4.4.3, Cost Comparison of this report. If digging were limited to category 1–5 targets, approximately half as many targets

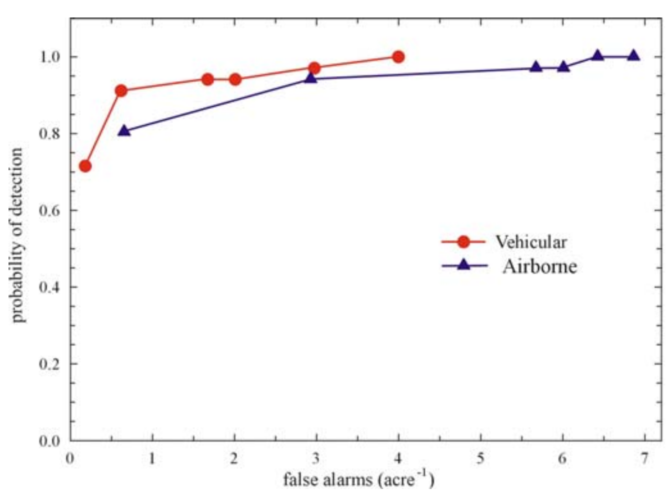

Figure 12. ROC Curves for the Vehicular and Airborne Surveys on the 110-Acre Common Survey Area.

would have to be dug behind the vehicular survey. Another way of visualizing this information is with a plot called the receiver operating characteristic (ROC). Figure 12 shows a comparison of the ROC curves for the 110-acre surveys common to the vehicular and airborne systems.

4.3.2 Missed Targets

Table 8 shows data relating to the inert targets in the Seed Target Area. This information enables comparisons of the performance of the airborne and vehicular arrays. Each survey approach led to selection and analysis of all the inert targets. Target 254 (an 8-in projectile) has also been included, although it was buried just north of the Seed Target Area. The live 155-mm projectile (target 104) is also included. The vehicular magnetometer array, because it produces very high-density sensor data, generates more accurate location predictions. An average deviation from the ground truth of 15 cm is typical.

The sensor data from the airborne system has about one tenth the density of the vehicular data, but this data density is still sufficient to provide location accuracies of better than 25 cm. The ground truth data, compiled by ERDC, provide the depth to the shallowest part of the buried item. The MTADS DAS predicts the depth to the center of the target. With the exception of target 86 (large remnant moment) and target 121 (overlaid by shrapnel), all ordnance items were categorized as 1, 2, or 3.

Table 8. Vehicular and Airborne Survey Comparisons with the Ground Truth in the Seed Target Area.

MTADS ID	Survey	UTM X(m)	UTM Y(m)	I XY (m) Vehicular Mag	I XY (m) Airborne Mag	Depth (m)	Size (m)	Moment	Incl	Azi	Fit Quality	Analyst Comments	UXO Category
G3S-13	Vehicular Mag	722,808.40	4,838,032.85	0.11		0.63	0.125	1.1133	71	261	0.952	poor degaussing?, 105, nose down	2
	Airborne Mag	722808.47	4838032.75		0.02	0.34	0.135	1.4079	61	235	0.983	105/155mm	1
	Ground Truth	722808.48	4838032.77			0.30	105 mm		45	360		Nose Down	
G3S-26	Vehicular Mag	722,889.71	4,838,018.86	0.53		1.09	0.166	2.6054	88	147	0.942	likely 155, nose down	1
	Airborne Mag	722890.06	4838019.21		0.35	0.51	0.153	2.0426	67	43	0.950	155mm	1
	Ground Truth	722889.76	4838019.39			0.50	8 in		40	340		Nose Down	
G3S-59	Vehicular Mag	722,957.47	4,838,064.38	0.17		0.88	0.147	1.8154	82	170	0.975	good fit for a 155	1
	Airborne Mag	722957.83	4838064.09		0.38	0.21	0.144	1.6945	68	154	0.949	155mm	1
	Ground Truth	722957.64	4838064.41			0.25			80	315		Nose Down	
G3S-65	Vehicular Mag	722,914.61	4,838,051.01	0.08		0.78	0.101	0.5827	85	198	0.719	possible 105	3
	Airborne Mag	722914.59	4838050.95		0.03		0.127	1.1597	67	260	0.935	105/155mm	1
	Ground Truth	722914.61	4838050.93			0.30	105 mm		35	25		Nose Down	
G3S-86	Vehicular Mag	722,802.70	4,838,086.48	0.06		0.70	0.217	5.8345	-69	282	0.950	totally inverted, fence post?	5
	Airborne Mag	722802.81	4838086.55		0.09	0.22	0.210	5.3199	-61	268	0.988	fence post	5
	Ground Truth	722802.76	4838086.48			0.25	155 mm		65	250		Nose Down	
G3S-88	Vehicular Mag	722,848.53	4,838,066.46	0.14		0.73	0.204	4.8764	75	355	0.947	good fit for 8in	1
	Airborne Mag	722848.53	4838066.12		0.20	0.51	0.215	5.6443	83	29	0.964	8 in	1
	Ground Truth	722848.56	4838066.32			0.25	155 mm		70	165		Nose Down	
G3S-89	Vehicular Mag	722,834.26	4,838,082.69	0.15		0.73	0.192	4.0375	29	15	0.962	155mm/8in, good target	1
	Airborne Mag	722834.18	4838082.60		0.13	0.14	0.185	3.6480	28	15	0.989	155/8in	1
	Ground Truth	722834.30	4838082.55			0.30	8 in		0	10		Flat	
G3S-99	Vehicular Mag	722,926.09	4,838,070.01	0.03		0.88	0.141	1.6053	74	222	0.969	105, nose down	1
	Airborne Mag	722926.01	4838069.93		0.13	0.46	0.140	1.5677	69	240	0.975	155mm	1
	Ground Truth	722926.09	4838070.04			0.50	105 mm		60	65		Nose Down	
G3S-104	Vehicular Mag	722,958.73	4,838,109.38			0.83	0.164	2.5117	31	28	0.974	155mm	1
	Airborne Mag	722958.63	4838109.24			0.90	0.156	2.1599	30	18	0.950	155mm	1
	Vehicular EM	722958.81	4838109.32			0.70	0.168		15	-210	0.976	mag 104	Live 155mm
G3S-109	Vehicular Mag	722,901.28	4,838,106.51	0.06		1.10	0.209	5.2247	72	270	0.956	8-in, E/W	1
	Airborne Mag	722901.15	4838106.79		0.34	0.49	0.196	4.2892	58	294	0.976	8 in	1
	Ground Truth	722901.24	4838106.46			0.55	155 mm		45	75		Nose Up	
G3S-112	Vehicular Mag	722,874.50	4,838,117.74	0.09		1.34	0.225	6.5351	84	254	0.969	8-in deep	1
	Airborne Mag	722874.44	4838117.79		0.03	1.13	0.242	8.1181	74	242	0.961	8 in	1
	Ground Truth	722874.46	4838117.82			0.75	8 in		80	40		Nose Down	
G3S-118	Vehicular Mag	722,830.52	4,838,118.83	0.07		1.34	0.177	3.1792	75	65	0.918	155 deep, nose down	1
	Airborne Mag	722830.60	4838118.90		0.18	0.35	0.130	1.2576	81	62	0.962	155mm	1
	Ground Truth	722830.47	4838118.78			0.60	105 mm		75	245		Nose Up	
G3S-121	Vehicular Mag	722,786.29	4,838,121.08	0.29		0.90	0.092	0.4383	44	4	0.867	clutter	6
	Airborne Mag	722786.84	4838120.64		0.42	0.35	0.094	0.4786	54	45	0.946	unlikely 105	3
	Ground Truth	722786.50	4838120.88			0.85	155 mm		45	0		Nose Down	
G3S-127	Vehicular Mag	722,818.86	4,838,143.80	0.20		1.32	0.112	0.8004	65	329	0.910	really deep 105?	2
	Airborne Mag	722818.82	4838143.58		0.23	0.63	0.104	0.6485	71	333	0.956	105mm	1
	Ground Truth	722819.03	4838143.69			0.85	155 mm		45	115		Nose Down	
G3S-132	Vehicular Mag	722,860.18	4,838,142.72	0.06		0.55	0.132	1.3152	45	316	0.983	likely 105	1
	Airborne Mag	722860.15	4838142.55		0.14	0.05	0.132	1.3232	44	309	0.972	155mm	1
	Ground Truth	722860.13	4838142.69			0.25	155 mm		0	110		Flat	
G3S-133	Vehicular Mag	722,893.48	4,838,141.68	0.10		0.65	0.117	0.9054	55	251	0.960	105, slight remnant	2
	Airborne Mag	722893.51	4838141.52		0.21	0.37	0.127	1.1689	55	248	0.912		
	Ground Truth	722893.58	4838141.72			0.50	105 mm		55	50		Nose Down	
G3S-135	Vehicular Mag	722,919.68	4,838,136.81	0.37		1.01	0.133	1.3313	69	54	0.874	105mm, nose down	1
	Airborne Mag	722919.49	4838136.59		0.48	0.30	0.113	0.8177	79	66	0.961	105mm	1
	Ground Truth	722919.42	4838137.07			0.40	155 mm		55	310		Nose Down	
G3S-139	Vehicular Mag	722,957.75	4,838,142.70	0.19		1.10	0.210	5.2659	70	84	0.981	8-in, E/W	1
	Airborne Mag	722957.80	4838142.46		0.32	0.56	0.203	4.7531	62	99	0.983	8in nearly nose down	1
	Ground Truth	722957.56	4838142.67			0.50	8 in		45	270		Nose Down	

Table 8. Vehicular and Airborne Survey Comparisons with the Ground Truth in the Seed Target Area. (continued)

MTADS ID	Survey	UTM X(m)	UTM Y(m)	Ĭ XY (m) Vehicular Mag	Ĭ XY (m) Airborne Mag	Depth (m)	Size (m)	Moment	Incl	Azi	Fit Quality	Analyst Comments	UXO Category
G3S-142	Vehicular Mag	722,931.84	4,838,164.64	0.02		0.58	0.101	0.5826	34	30	0.954	105mm	1
	Airborne Mag	722931.77	4838164.94		0.29	0.00	0.093	0.4570	30	23	0.927	105mm	2
	Ground Truth	722931.82	4838164.65			0.25	105 mm		0	30		Flat	
G3S-148	Vehicular Mag	722,886.96	4,838,168.65	0.06		0.79	0.156	2.1836	63	188	0.986	155mm	1
	Airborne Mag	722886.83	4838168.91		0.25	0.25	0.152	2.0118	84	262	0.988	155mm	1
	Ground Truth	722886.90	4838168.67			0.30	155 mm		35	360		Nose Down	
G3S-149	Vehicular Mag	722,879.12	4,838,174.30	0.15		0.67	0.138	1.5182	51	312	0.982	105/155mm, E/W, nose down	1
	Airborne Mag	722879.38	4838174.22		0.15	0.26	0.138	1.4937	59	307	0.989	155mm E/W	1
	Ground Truth	722879.23	4838174.21			0.40	105 mm		45	115		Nose Down	
G3S-152	Vehicular Mag	722,831.29	4,838,176.14	0.16		1.33	0.146	1.7633	82	90	0.939	possible deep 155	2
	Airborne Mag	722831.82	4838176.25		0.40	0.46	0.119	0.9520	74	96	0.965	105	1
	Ground Truth	722831.42	4838176.23			0.92	105 mm		75	5			
G3S-153	Vehicular Mag	722,824.52	4,838,171.35	0.22		1.21	0.148	1.8602	90	356	0.970	probable deep 155	1
	Airborne Mag	722824.43	4838171.26		0.32	0.52	0.137	1.4690	84	195	0.968	155mm	1
	Ground Truth	722824.74	4838171.34			0.75	8 in		75	350		Nose Down	
G3S-154	Vehicular Mag	722,813.23	4,838,176.30	0.05		1.36	0.235	7.4160	87	3	0.941	deep 8-in, nose down	1
	Airborne Mag	722813.49	4838176.36		0.22	0.55	0.193	4.1193	89	147	0.988	8 in	1
	Ground Truth	722813.27	4838176.31			0.60	155 mm		80	15		Nose Down	
G3S-163	Vehicular Mag	722,853.25	4,838,196.21	0.17		0.65	0.135	1.4049	47	299	0.972	155mm, E/W	1
	Airborne Mag	722853.20	4838196.21		0.22	0.37	0.149	1.8740	43	301	0.960	155mm E/W	1
	Ground Truth	722853.42	4838196.19			0.25	105 mm		35	110		Nose Down	
G3S-167	Vehicular Mag	722,921.08	4,838,201.86	0.29		1.01	0.108	0.7287	64	359	0.921	possible deep 105mm	2
	Airborne Mag	722921.44	4838202.25		0.25	0.42	0.106	0.6742	40	38	0.895	possible 105	3
	Ground Truth	722921.32	4838202.03			0.60	155 mm		40	30		Nose Down	
254	Vehicular Mag	722792.22	4838243.01	0.08		1.40	0.233	7.2576	79	189	0.973	great 8-in signature	1
	Airborne Mag	722792.37	4838243.13		0.15		0.213	5.73206	79	100	0.977	8-in	1
	Ground Truth	722792.23	4838243.09			0.65	8-in		285	75		Nose Down	

4.4 TECHNOLOGY COMPARISON

4.4.1 Technical Performance

In this section, we present a comparison of the technical performance of the vehicular and Airborne MTADS platforms with respect to system reliability, speed, ease of use, etc. This demonstration was the first use of the Airborne MTADS to conduct an extensive survey. On the Impact Area, the airborne hardware performed flawlessly in the field, and the data processing, analysis, and target picking performance was routine, exceeding our expected production rates.

The vehicular magnetometer array has been deployed on a dozen large sites. Its performance is reliable and predictable, partly the result of system design, but more importantly, it is the result of careful and extensive attention to maintaining a comprehensive inventory of system spares and our ability to effectively recover from breakdowns in the field by making innovative decisions and tackling mechanical, hardware, or software fixes on the fly. We have used this same resilience in design and the redundancy in spares with the airborne system. It is worthwhile to note that in the field, on the first day of airborne surveying, we built new mounting fixtures, installed new GPS antennas, and changed out one of the magnetometers (with its interfaces and cable runs) with parts from our spares inventory.

The production rates of the airborne system were 300–500 survey acres per day under the conditions of this site. The corresponding production rates for the vehicular MTADS are routinely 18–24 acres per day. This ratio of production rates of a factor of 15 in favor of the

airborne system will likely hold across a wide range of site conditions. The production rates with the vehicular system would be much lower if terrain conditions were significantly more difficult. Production rates with the airborne system will significantly suffer only if the sites chosen for its use are very small or if very short flight lines must be flown with difficult turn-arounds.

4.4.2 Cost Performance

Table 9 presents a cost breakdown for a hypothetical 1,500-acre survey on a relatively benign site typified by the IA at the BBR. We assume that the site is a UXO range, that we have to establish navigation control points, that the site would not benefit from a preliminary surface sweep/clearance, that a 1,000-mile ferry of equipment is required, that we have to provide all logistics support, that data will be processed and analyzed on site and that a target list will be prepared, that we are not supporting any target remediation, and that a report (typical of an ESTCP demonstration report) will be retrospectively written. During the survey operation, our daily, on-site costs are ≈ $15,000. For the purposes of scaling the size of the survey (probably up to 3,000 or 4,000 acres), one should be able to assume 400 acres/day of survey at the nominal daily costs. A safe projection should be ≈ $50 per additional acre.

Table 9. Projected Costs for a 1,500-Acre Airborne MTADS Survey.

Preparation and Startup		Site Operations (Assume 1-Week Operation)		Mobilization/Demobilization	
Activity	**$K**	**Activity**	**$K**	**Activity**	**$K**
Site visit and inspection	4	Three rental vehicles	2	Rental truck	5
Preparation of test plan, maps, photos, etc.	15	Supervisor**(1260+160)X7	10	Rental truck driver (6 travel days) (850+160)X6	6
Establish control points	6	Helicopter/back seat (850+160)X7	7.5	Helo ferry cost	12
Capital equipment*	-	Analysis support (two persons) (850+160)X7X2	15	Helo ferry pilot (800+160)X2 (2+0.5X8)2	2
Permitting and regulatory requirements	-	Pilot (5 days) (800+160)X5	5	Three workers' travel (assume one in the truck)	10
On-site logistics		Charter (2 days setup, tear down, calibration/training)	6	Analysis	15
Office trailer electrician, power, fuel	12	Charter (3 days survey), (2+0.5X8)3	18	Report	25
Security	3	Helo fuel truck/fuel (2800+300X2)	3.4		
Materials	2				
Portable toilets	0.5				
Subtotal	42.5		66.9		75

* MTADS equipment is not expensed or amortized for this exercise.

** Personnel costs include per diem; 7-day operation assumed unloading, setup, cleanup, etc.

4.4.3 Cost Comparison

Excluding the cost of the report, the cost of the hypothetical 1,500-acre airborne survey projected in Table 9 is $106/acre. In this section, we consider the relative costs of a vehicular MTADS survey and remediation compared to using the airborne system. Assume the same 1,500 acre range as included in the airborne survey described in Table 9. The hypothetical vehicular survey uses one fewer support person than we actually used at the IA, but the daily salary and per diem costs are ≈ 20% higher than were paid in 2001 at the IA, in line with those used in the airborne calculation, reflecting current rates.

In most surveys with the vehicular MTADS, covering 20 acres per day in hospitable areas is routine. Because this is a very extended survey for a single vehicular system, we assume that the weekends must be reserved for maintenance and repair and to make up for weather delays. Therefore, surveying 1,500 acres with the vehicular MTADS is projected to require ≈ 75 days or 16 five-day weeks. Assuming 1-month personnel rotations for the supervisor, the vehicle driver, and the two-man analysis trailer crew, and assuming that this staff is supported by three OST members, we made the cost projections shown in Table 10. The projected survey costs are $581,000, or $390/acre.

Table 10. Projected Costs for a 1,500-Acre Vehicular MTADS Survey.

Preparation and Startup		Site Operations (Assume 16-week operation)		Mobilization & Demobilization	
Activity	**$K**	**Activity**	**$K**	**Activity**	**$K**
Site visit/inspection	4	Three rental vehicles (4x4 for 16 wk)	32	Rental trailer truck	10
Preparation of test plan, maps, photos, etc.	15	Supervisor** ([1260/day]5+[160/day]7)x16wk	119	Rental truck driver (6 travel days) (850+160)X6	6
Establish control points	6	Analysis support (two persons) ([850/day]5+[160/day]7x16wk) two persons	172	Five airfare round-trips x four rotations	20
Capital equipment*	-	Driver/support ([850/day]5+[160/day]7x16wk)	86	Truck driver, one air round-trip	1
Permitting and regulatory requirements	-	Fuel, vehicle repair, maintenance	6	Equipment repair, restock	10
On-site logistics		OST support	32		
Office trailer, electrician, power, fuel	25			Report	15
Security	-				
Materials	5				
Portable toilets	4				
Tent cover	3				
Tribal subcontracting	10				
Subtotal	72		447		62

*MTADS equipment is not expensed or amortized for this exercise

** Personnel costs include per diem, 80-day operation assumed unloading, setup, cleanup, etc.

During the remediation of the IA in 2001, we dug 471 vehicular targets and 527 airborne targets for a total of 998. Remediation operations, including way pointing, digging, blowing, sorting, certifying, and disposal of scrap, cost $200,000. Equipment rental costs were $20,000; the GPS equipment, already on site, was considered rent free. Target recovery costs were therefore $220/target. This is in line with our typical costs of ≈ $200/target.

On the IA, 1,565 acres were surveyed, including the 110-acre vehicular survey area and the remaining 1,455 acres of the airborne survey area that were analyzed and remediated based on the airborne survey. A total of 1,938 targets (1,193 + 790) were specified from the airborne analysis (in all priority categories). The ratio of vehicular to airborne targets picked on the vehicular survey areas was 471/790. On this basis, we project that there would be 1,182 targets (471/790 x 1,983) to remediate if the vehicular MTADS were used to survey all 1,565 acres. This information is summarized in Table 11. Without the requirement to extensively document the dig sheets and maintain a digital photographic log of all dug targets, we estimate that targets could be dug at a cost of $200 per target.

The predicted total survey and clearance costs of $563,000 for the airborne operation are realistic because they closely reflect actual survey, analysis, and remediation costs. The vehicular survey and analysis values are more hypothetical. We have never undertaken a vehicular operation of this magnitude. It was costed based on our use of engineers and Ph.D.s to staff the analysis trailer and supervise field crews. In a realistic commercial vehicular survey, manpower costs would be lower on a dollar/hour basis. It is conjectural as to whether the 20-acres-per-day survey rates could be attained (or maintained) with less qualified, less motivated crews.

Table 11. Hypothetical Survey and Remediation Costs (in $K) **for a 1,565-Acre Survey on the BBR Impact Area.** (Primary cost entries assume all targets are dug. Costs in parentheses assume that only category 1–5 targets are dug.)

Airborne Clearance	$K	Vehicular Clearance	$K
Projected survey cost	166.4	Projected survey cost	581.0
Projected cost to clear 1,983 targets	396.6 (371.1)	Projected cost to clear 1,182 targets	236.4 (180.6)
Total airborne survey and remediation costs	563.0 (526.8)	Total vehicular survey and remediation cost	817.4 (761.6)

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5.0 ABERDEEN PROVING GROUND DEMONSTRATION DESIGN

5.1 PERFORMANCE OBJECTIVES

The objectives of this demonstration were established and defined by APG in their Wide Area UXO Aerial Demonstration and Survey Project[29] as documented in their demonstration test plan.[20] Multiple sites at APG were established to evaluate the performance of the NRL Airborne MTADS in comparison with the U.S. Army Corps of Engineers (USACE)/Huntsville-ORNL airborne system (ESTCP Projects UX-0037 and UX-0101). The APG demonstration test plan[20] specified that each system would fly the same survey areas during the same demonstration period. Survey products from both the NRL and ORNL surveys were to be submitted to the AEC, ESTCP, and the Institute for Defense Analyses (IDA) for evaluation. Five survey ranges were prepared, in addition to a small calibration area with known UXO challenges. To augment existing UXO and clutter, which was present on four of the five survey areas, the U.S. Army Aberdeen Test Center (ATC) emplaced additional inert seed UXO on three of the survey areas, ranging in size from 60-mm mortars to 155-mm projectiles. Specific objectives[12] included demonstrating the following:

- The detection capability on a relatively low-clutter area seeded with small and medium-sized UXO
- The detection and discrimination capabilities on a mixed-use range with relatively flat terrain and low vegetation levels
- The detection and discrimination capabilities on a very complex, mixed-use range with areas of 2-m high vegetation, transitions to shallow water, high levels of surface clutter and obstacles, and expectations of buried UXO caches
- The UXO detection capability in freshwater ponds seeded with ordnance
- The UXO detection capability on a marine projectile impact area with water depths of 0–2.5 m.

Performance goals were conducting efficient airborne surveys; analysis of data, including differentiation of UXO from clutter; and preparation of data products, including target reports and ranked analysis results.

5.2 PERFORMANCE METRICS

5.2.1 Target Location Accuracy

The surveys were conducted with Airborne MTADS using GPS navigation; dual GPS antennas; and acoustic, laser, and radar altimeters. Three of the sites were seeded with inert ordnance, and the ground truth for the site was held by ATC until after the analysis results had been submitted.

5.2.2 System Operational Performance

Field logs, kept for all survey activities, provided information about setup times, survey times, production rates, and equipment performance. The electronic data files provided additional

information about field survey performance by documenting survey data collection times, the course used in data collection, stoppages during data collection, how turnarounds were accomplished, and how precisely the pilot completed the planned survey grid. Missed areas were determined and difficulties with navigational data were documented, and, where possible, corrected.

5.2.3 Detection Capability

This demonstration further tested the Airborne MTADS' ability to differentiate between clutter and ordnance on land and was the first use of the airborne system to conduct UXO surveys over water. Because the sensors on an airborne platform must be deployed farther from the ground surface than those on vehicular or man-portable systems, it is understood that detection sensitivity for single, smaller UXO items is compromised. In an airborne survey, the sensors are 4 to 20 times more distant from the ground surface than in a vehicular survey. The primary effects of this are a significantly decreased peak signature intensity and a substantial spreading of the dimensions of the anomaly signature in the airborne data.

5.3 SELECTING TEST SITES

The criteria and requirements leading to the choice of test sites for this demonstration are explained in the APG demonstration test plan. In general, the site managers selected areas that had different UXO challenges (ranging from antipersonnel submunitions to large general purpose (GP) bombs), various densities of targets and clutter, different types of terrain, and varying difficulties of access (vegetation, water, stockpiled munitions, heavy machinery, etc.). The individual survey areas were small by airborne survey standards, varying from much less than an acre to slightly over 100 acres. Therefore, there was no significant possibility of evaluating the economies of the airborne system compared to land-based approaches.

5.4 TEST SITE HISTORY AND CHARACTERISTICS

A description of the impact ranges and the prepared test sites at APG is provided in the demonstration test plan[20] prepared by APG. Information pertinent to our specific operations is briefly reviewed in Sections 4.6.2.2, 4.6.2.3, 4.6.2.4, and 4.6.2.5 of the plan.

5.5 PHYSICAL SETUP AND OPERATIONS

5.5.1 Site Preparation

The only site preparation work carried out specifically in preparation for these demonstration surveys was the burying of seed and calibration targets at the Airfield, and seed targets at Active Recovery Field, the Chesapeake Bay Impact Area, and the dewatering ponds. The seed targets were not buried at the water sites but were placed flush with the bottom sediments.

The five test sites chosen by APG comprise parts of four current or former impact ranges and a prepared site at the Airfield. At three of the sites—the Airfield, Mine, Grenade, and Direct-Fire Range, and offshore areas of the Bay Impact Area—selected target areas were seeded by ATC with inert ordnance. Seed targets specified in the APG demonstration test plan 20 included 60-mm and 81-mm mortars, 2.75-in rocket warheads, and 105-mm and 155-mm projectiles.

5.5.2 Changes in the MTADS

The changes in the MTADS following the Badlands Bombing Range demonstration included the implementation of software routines to produce a digital elevation model (DEM) using the MTADS altimeters and the modifications in the DAS to present the analyst with a real-time depth fit for analyzed targets. In addition, a utility was created to save the selected data clips used for target analysis and the values for the maximum positive and negative signal intensities for fit targets. This information was requested by the Program Office specifically for the APG demonstration.

5.6 ANALYTICAL PROCEDURES

Survey data were inspected on site, at offices provided in the pilot's ready lounge at the Airfield, using notebook computers running the Windows version of the Airborne MTADS DAS. Separate project files were established for each survey and individual sortie files were integrated into single master files for each of the survey projects. The only areas resurveyed during the demonstration were the calibration and seed target sites at the Airfield. The initial data taken at these sites were primarily used for pilot orientation and equipment checkout and were not used in target analysis.

Each data file was edited to remove data from aircraft turnarounds and from well outside the survey boundaries. Sensor data were inspected and spurious data points were edited from the files. A 500-point (5-second) demedian filter was applied separately to each sensor track. This suppressed zero-offset differences among the sensors, long-term sensor drift, heading offsets, and large-scale geology effects. A notch filter (at 6.45 Hz and 12.9 Hz) was applied to suppress blade- (rotor hub) induced noise and (at 25 Hz) to suppress platform vibration noise. The notch-filter widths and roll-offs were adjusted and applied equally to all sensors. Values were chosen to null blade noise from the two outboard sensors at each end of the array. The three center sensors, which were closer to the blade footprint, retained minimal blade-based noise at a level that did not interfere with analysis of the smallest (60 mm) expected targets. All data processing and target analysis took place subsequent to the end of the fieldwork. Each data set was processed using the same approach and evaluation parameters by a single analyst who also prepared all dig lists and report products.

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6.0 ABERDEEN PROVING GROUND PERFORMANCE ASSESSMENT

6.1 PERFORMANCE DATA

6.1.1 The Airfield Survey

Target analysis was carried out using the MTADS DAS. Raw data were processed as described in Section 4.6.8.1 of the final report, Airborne UXO Surveys Using the MTADS. The initial target analysis assumed that the smallest targets of interest were 60-mm mortars and the largest were 155-mm projectiles. As the survey image in Figure 13 shows, there are many magnetic anomalies on this site that are significantly larger than 155-mm projectiles. Buried utilities, likely conduits for runway landing lights, lie roughly parallel to the east, south, and west survey boundaries. On the south, the utility run lies beyond the limit of the survey. However, both the east and west boundaries of the survey include the utility runs. Many of the larger signals associated with these features are unlikely to involve UXO; however, in the northwest corner of the site, there is a significantly disturbed area in which the aerial photo and the DEM both show features that resemble craters. The magnetic anomaly map shows that significant magnetic signatures are associated with many of these features. In addition, there are a few dozen isolated substantial target returns within the survey area that could be large UXO. Therefore, our analysis reports both targets in the seed target size range and others that are too large to be 155-mm projectiles.

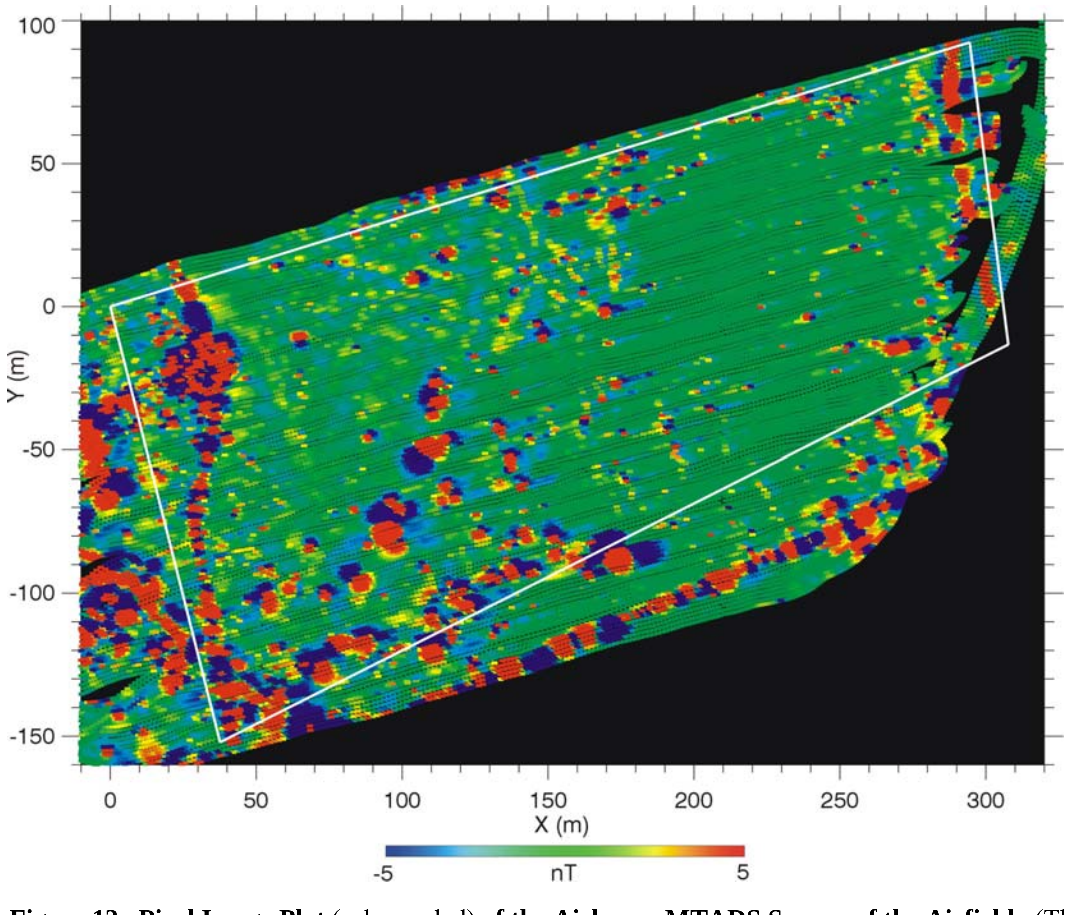

Figure 13. Pixel Image Plot (subsampled) **of the Airborne MTADS Survey of the Airfield.** (The white border defines the limits of the survey. See Figure 25 in the final report for the digital orthoquad [DOQ] and DEM presentations.)

The target list includes both small and large targets. The probability that an individual target in this list is one of the seed targets is ranked using the six-category subjective analysis criteria established during the Jefferson Proving Ground demonstrations. All large targets in the survey area are included in the target report, even though many are clearly too large to be members of the class of seed targets. The column in the target report labeled “Probability as UXO Seed” evaluates the data on the basis of there being only five ordnance types of interest on the site. A probability of 5 or 6 for a very large target indicates a very low probability of that object being a seed target; the probability of that object being a UXO larger than the class of seed targets may be significantly greater.

The first 318 targets in the Airfield target report are those included in the initial submission based upon 60-mm mortars being the smallest UXO of interest on the site. The data were reanalyzed, as directed by the Program Office, to pick targets down to the system or site noise limit following reprocessing of the data as described above. Targets 319–618 resulted from the follow-up analysis.

6.1.2 System Performance at the Airfield

The IDA analysis and report of the demonstration performance at APG summarizes the site information and detection performance. Table 12 shows that 52 inert UXO, primarily 81-mm mortars and 105-mm projectiles, were seeded into the prepared range. IDA considered the effects of using 1.0 m, 1.5 m, and 2.0 m halos on detection performance and 94% of the MTADS’ correct declarations were captured in the 1.0 m halo. Figure 14 presents this information (for a 1.5 m detection halo) in a ROC curve format. All target declarations were made using the six-category probability scale. These probability bins were used to construct the ROC curve. Overall, the MTADS correctly identified slightly more than 94% of the UXO.

Table 12. Ordnance Detection Results for the Airfield Open Area for Three Detection Halos.*

Ordnance	Emplaced	1m	1.5m	2m
60-mm	3	3	3	3
81-mm	21	16	18	18
105-mm	28	27	28	28
Total	52	46	49	49

*Adapted from Table 5 of Reference 21

6.1.3 The Active Recovery Field Survey

The survey of the Active Recovery Field covered ≈ 100 acres. The magnetic anomaly image is shown in Figure 15. This highly contaminated site (see Figures 31 and 32 in the final report, Airborne UXO Surveys Using the MTADS) is characterized by clusters of large and small ordnance; stockpiles of recovered ordnance and scrap; an extremely dense ordnance deposit stretching for more than 200 m

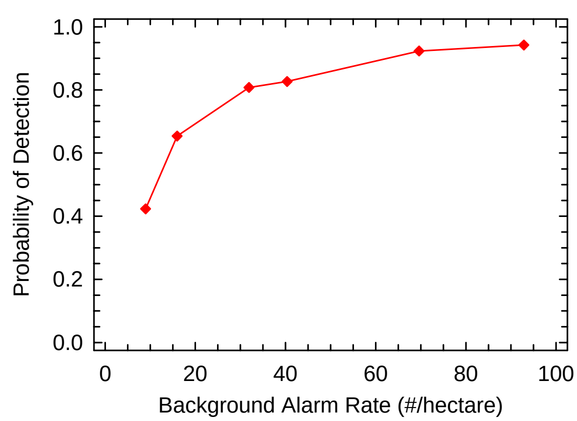

Figure 14. ROC Curves for the Airfield Open-Field Area for a 1.5 m Halo.

and lying offshore in the bay parallel to the shoreline; areas of dense, 6-ft-tall vegetation; and by several steel blast shields and scattered heavy equipment. It was within this context of signal returns many times larger than a signal generated by a 155-mm projectile that data analysis was carried out. Where background levels allowed, targets were analyzed to the size level that would include 60-mm mortars. The target analysis of this survey required >100 hours of analysis time. The IDA report discloses that 64 seed targets were buried amidst the clutter at the Active Recovery Field. Tables 13 and 14 summarize the detection results for the airborne surveys. NRL declared 2,969 targets.. The detection efficiency at this site was only marginally above random chance.

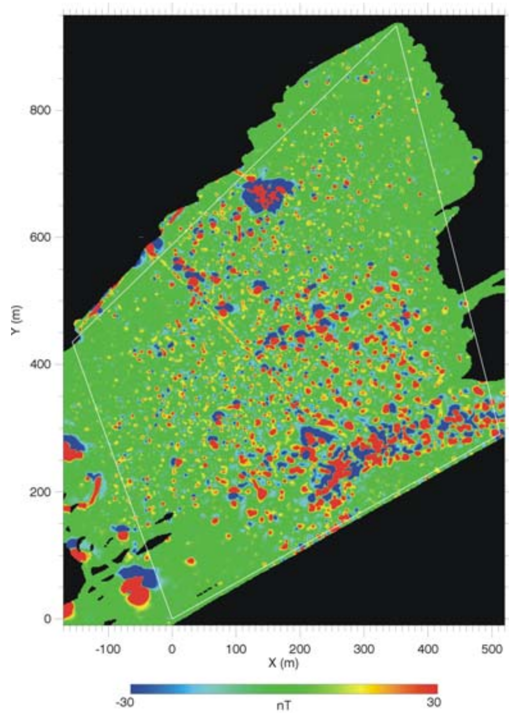

Figure 15. Magnetic Anomaly Image (interpolated) of the Active Recovery Field. (Note the cluster of surface ordnance at the top center, stockpiles of materials along the road, and the extended concentration of magnetic returns offshore.)

6.1.4 The Dewatering Ponds

The entire survey area at the dewatering ponds consisted of five freshwater ponds. Figure 16 shows a survey plot of the four small ponds called the Finger Ponds by APG. The image extends north and south, well beyond the ends of the ponds. There is a small missed survey area near the center of the south end of the westernmost pond and a small missed area (due to data dropout) on the western edge of the second pond from the east.

Table 13. Ordnance Detection Results for Active Recovery Field for Two Detection Halos.*

Ordnance	Emplaced	1 m	1.5 m
81-mm	32	0	1
105-mm	32	4	4
Total	64	4	5

*Adapted from Table 8 of Reference 21

Table 14. Cumulative Detection Probability as Function of Ordnance Likelihood Call for Active Recovery Field.*

UXO Likelihood	% detections	
	1-m halo	1.5-m halo
1	3.1	4.7
2	4.7	6.3
3	4.7	6.3
4	6.3	7.8
5	6.3	7.8
6	6.3	7.8

* Adapted from Table 9 of Reference 21

Figure 17 shows a magnetic anomaly image from the survey of the large pond at the eastern edge of the area. Most of the more intense signals are from objects lying at or beyond the banks of the pond. A much finer scale is required to visualize the UXO lying on the bottom of the pond.

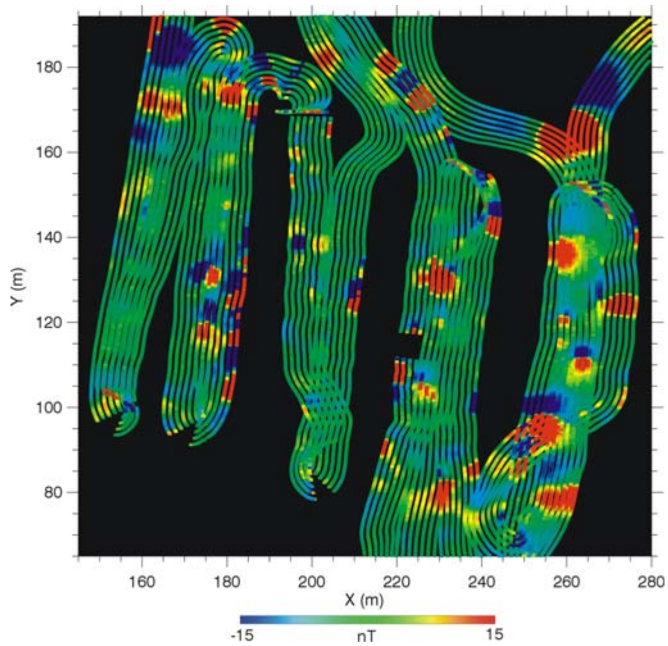

Figure 16. Pixel Image Plot of the Survey of the Finger Ponds.

Only about 130 of the 224 declared targets at the dewatering ponds are small enough to be seed targets, and many of these lie outside the pond areas. The larger targets and the targets beyond the pond shorelines are included in the target report because, in the APG Demonstration Test Plan, this survey area was claimed to be relatively free of clutter. This target information is provided so that the targets can be investigated if there is an interest in their identities. Table 15 shows the results from the IDA analysis and report. Forty-seven targets, mostly 81-mm mortars and 105-mm projectiles, were placed in the ponds. NRL's analysis declared 224 targets, as described above. At the dewatering ponds, the primary difficulty in identifying the targets resulted from the standoff distance between the targets and the sensors (the intervening water and air) rather than the background clutter, which interfered with detection at the Active Recovery Field.

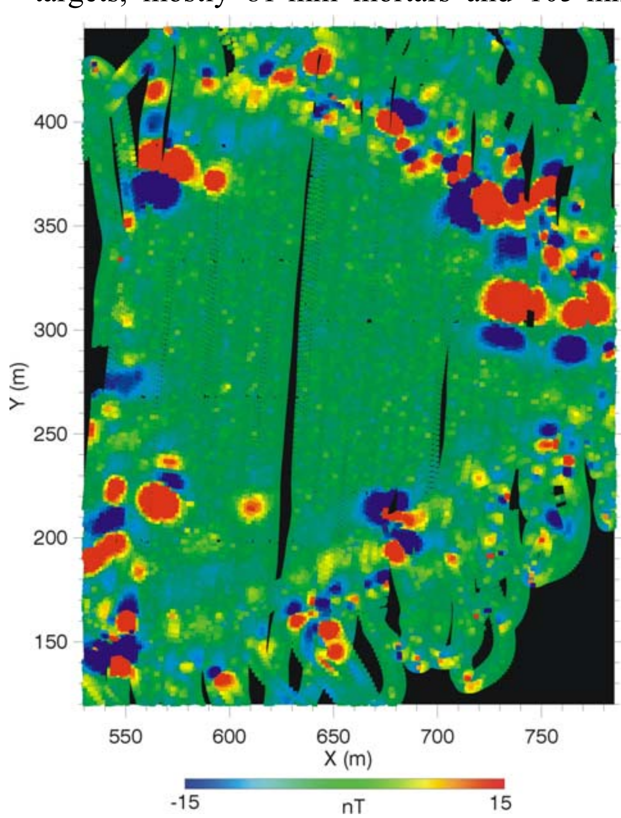

Figure 17. Magnetic Anomaly (subsampled, pixel) **Image from the Survey of the Large Dewatering Pond.**

Table 16 shows the ground truth coordinates for the seed targets emplaced in the five dewatering ponds. The center column, offset by double lines on the left and right, provides comments generated when the ground truth data was rationalized with the survey images.

The combined standoff distance of the helicopter above the water surface and the depth of the water above the seed targets rendered all of the 81-mm targets undetectable. Effectively, all of the 105-mm and 155-mm targets were detected in the small ponds. One target (FP-105MM 2) was missed because its easting coordinate had been recorded incorrectly in the target report.

Table 15. Cumulative Detection Probability as a Function of Ordnance Likelihood Call for the Pond Surveys.*

UXO Likelihood	% detections	
	1-m halo	1.5-m halo
1	19.1	19.1
2	25.5	29.8
3	27.7	31.9
4	27.7	31.9
5	27.7	31.9
6	27.7	31.9

* Adapted from Table 7 of Reference 21.

The ground truth for the dewatering ponds seed targets was provided by Mr. Gary Rowe. Its release was delayed to allow demonstration tests of other systems on the ponds. The coordinates and identifications of the seed targets are provided in Table 16, which also provides information on the targets that were detected in the MTADS survey. We reexamined the signatures of the targets that were not detected, and in the center column of the table, we provide our observations.

6.1.5 The Mine, Grenades, and Direct-Fire Range

The Range, shown in Figure 18, was the largest of the survey areas at 130 acres. A north-south paved road that is apparent in the magnetic anomaly image bisects the survey. To the west of the road is a series of gravel roads leading to target pads. During the Airborne MTADS survey, the pads were not occupied. The bluestone used to construct the gravel roads and pads is very magnetically active. Figure 19 shows part of the upper road and the target pad. The individual target anomalies, ranging in size from fuzes and antipersonnel ordnance to GP bombs, are generally clustered about the target pads. The large amount of missed area along the south-eastern side of the survey was the result of the tree cover. The easternmost tip of the survey is dominated by high signal returns. Much of this area, as observed during the survey, is characterized by construction rubble from previously existing structures.

Seed targets were not placed in this area. Therefore, the analysis was carried out assuming that the survey was in preparation for cleanup of a mixed-use range. The target report contains almost 3,400 targets. There are eight areas that we considered to be too densely cluttered to successfully analyze. If these areas are designated for clearance, they should be surface cleared and then surveyed using either the man-portable or the vehicular MTADS magnetometer arrays. The much higher density data would enable targets to be analyzed more accurately. Much of the remainder of the survey area could be effectively remediated (*not cleared*) using the airborne survey and analysis.

Table 16. Ground Truth for the Targets Emplaced in the Five Dewatering Ponds.

Ground Truth						MTADS Assignment					
Location	**Target Number**	**Serial No.**	**Azi.**	**Depth (m)**	**Rationalize Ground Truth with Survey Data**	**MTADS Target ID**	**Depth DEM (m)**	**Size (m)**	**Moment**	**Fit Quality**	**Analyst Comments**
Large Pond	P-81MM 1	172	0	1.8	targ 114 is 1.5m East, overlaid with too many high passes						
	P-81MM 2	131	90	1.4	not picked, 3nT signal, lost in noise						
	P-81MM 3	127	45	1.4	no signal						
	P-81MM 4	170	0	1.8	lost to signal from huge targ 78						
	P-81MM 5	129	45	2.3	not picked, 4nT signal in 3nT noise						
	P-81MM 6	100	45	1.8	no signal						
	P-81MM 7	174	90	0.9	no signal						
	P-81MM 8	133	90	1.4	no signal						
	P-81MM 9	132	0	0.9	signal lost to targ 14 & 15						
	P-81MM 10	20	0	2.0	no signal						
	P-81MM 11	139	90	1.5	no signal						
	P-81MM 12	173	0	1.5	no signal						
	P-105MM 1	195	0	1.8	lost under target 115						
	P-105MM 2	178	90	0.9	target 247	247	1.45	0.096	0.4780	0.73	105mm
	P-105MM 3	210	45	1.8	target in missed area						
	P-105MM 4	200	0	2.3	no signal						
	P-105MM 5	189	0	1.8	no signal						
	P-105MM 6	207	45	1.8	no signal						
	P-105MM 7	162	45	2.1	no signal						
	P-105MM 8	197	0	0.9	target 246						
	P-105MM 9	161	45	1.4	target 243, 2 m South because it was 2 targets	243	3.53	0.147	1.7324	0.49	155mm
	P-105MM 10	145	45	0.6	target 241	241	0.59	0.091	0.4174	0.62	105mm
	P-105MM 11	186	90	0.6	target 242	242	0.95	0.085	0.3386	0.69	105mm
	P-105MM 12	172	90	1.2	I think targ 245 moved by 1.5 m	245	4.28	0.189	3.6878	0.59	medium target, deep
	P-105MM 13	138	0	2.4	no signal						
	P-105MM 14	159	90	2.4	lost in huge negative anomaly						
	P-105MM 15	174	0	1.8	lost in noise						
	P-105MM 16	179	45	1.8							
	P-105MM 17	221	45	2.0	lost in noise						
	P-105MM 18	134	90	2.1	lost in noise						
	P-155MM 1	111	0	1.7	target 79, likely moved ~ 1m	79	1.89	0.122	0.9859	0.70	155mm at 6 ft
	P-155MM 2	104	45	1.8	no signal, target moved?						
	P-155MM 3	105	90	0.9	target 14	14	1.75	0.142	1.5608	0.67	below
	P-155MM 4	Lost	90	2.4	lost in target 78 signal						
Small Ponds	FP-81MM 1	169	45	0.5	surrounded by 203, 204, 205, not picked						
	FP-81MM 2	123	45	0.3	not picked, 4nT signal in 2nT noise						
	FP-81MM 3	136	90	0.5	lost under target 164						
	FP-81MM 4	180	0	0.2	lost under target 154, 155						
	FP-105MM 1	141	0	0.3	target 191, too big for 105mm ?	191	1.79	0.172	2.7667	0.72	difficult fit, 155mm
	FP-105MM 2	147	0	0.3	target 189, my coordinate may be wrong in table	189	*				part signature, wont fit
	FP-105MM 3	140	90	0.8	target 187	187	0.19	0.088	0.3668	0.89	105mm/2.75in
	FP-105MM 4	198	45	0.3	target 202	202	0.17	0.102	0.5867	0.83	105mm
	FP-105MM 5	193	45	0.3	target 166	166	0.35	0.113	0.7857	0.93	105/155mm
	FP-105MM 6	171	0	0.3	target 168, shadowed by 167	167	1.21	0.236	7.2156	0.88	large deep taqrget
	FP-105MM 7	177	90	0.3	target 152	152	0.00	0.044	0.0452	0.70	shallow target, 60/81mm
	FP-105MM 8	185	90	0.3	target 153	153	0.38	0.072	0.2031	0.73	shallow, 81mm
	FP-155MM 1	106	45	0.6	target 186	186	1.64	0.287	12.8792	0.86	large target at 6 ft
	FP-155MM 2	109	0	0.6	target 164	164	0.41	0.183	3.3260	0.96	large shallow target, 155mm

To undertake a comprehensive UXO clearance of this range would require several clearances and resurveys. There is a substantial amount of small ordnance and aluminum ordnance visible on the surface. The final survey, therefore, should be done with an EM array, which would likely defeat the high magnetometer return from the bluestone pads and roads. From an economic point of view, if this area were designated for clearance, it would be more economical to start over. One should first conduct a surface clearance, repeat the magnetometer survey, dig targets, then survey with an EM array and dig targets again.

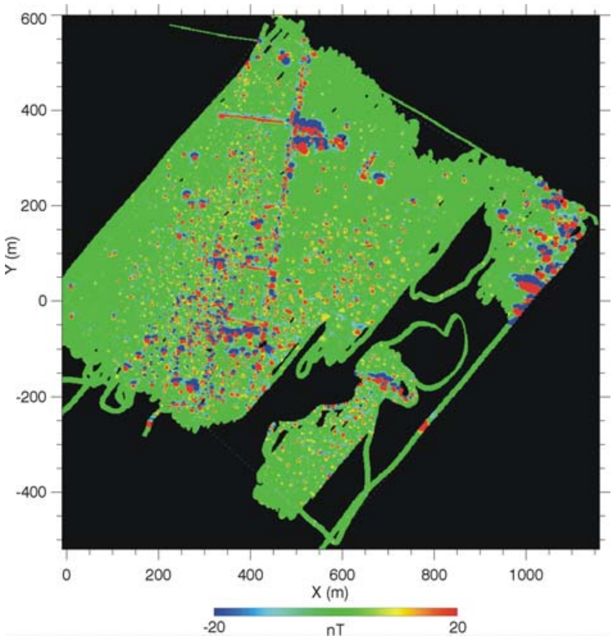

Figure 18. MTADS Survey Image of the Mine, Grenades, and Direct-Fire Range.

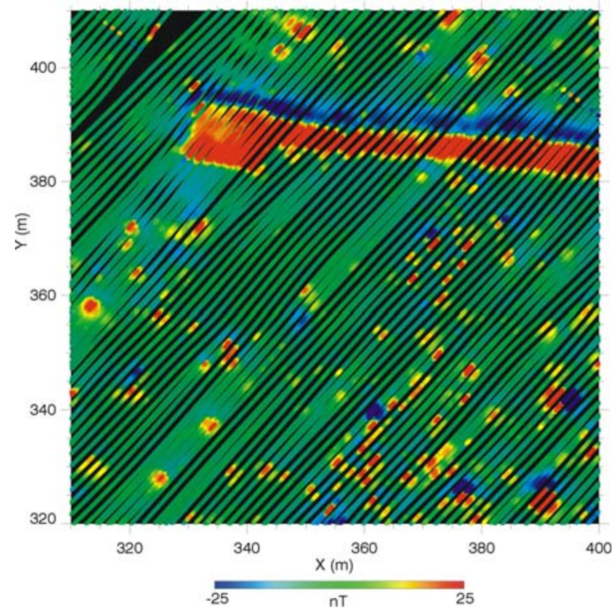

Figure 19. Magnetic Anomaly Image of a Portion of the Range Showing the Target Pad Near the North Corner of the Survey in Figure 18.

6.1.6 The Chesapeake Bay Impact Range

An interpolated magnetic anomaly image of the Chesapeake Bay survey is shown in Figure 20. The area surveyed was well offshore because we lost signal from the GPS base station and there was not another station available within line-of-sight for the helicopter to continue surveying closer to shore. The covered survey area included about 30 acres that provided a good estimation of the target density in the area.

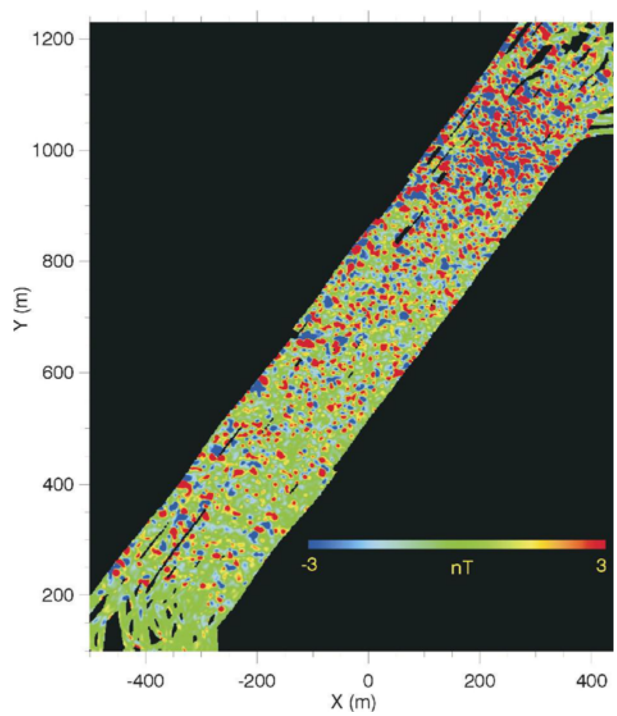

Figure 20. Magnetic Anomaly Image (interpolated) **of the Chesapeake Bay Impact Range Survey.**

The offshore target report contains 800 targets. The targets are much denser at the northeast end of the survey, although the entire survey area, as exemplified by Figure 21, reflects an impact area. Because of the significant standoff distance between the targets and the sensor boom, the target signatures spread and tended to overlap. Water depths were uncertain but were likely in the range of 2.5–6 ft. From the shape of the anomaly signatures and the analyzed target

depths, the water is probably shallower near the north end of the survey. The average analyzed target sizes are much larger than the 105-mm projectiles that were cited in the APG test plan as the likely dominant UXO. Because of the relatively large separation between the sensors and the targets buried in the sediment, larger targets are more visible in our analysis, and in some cases, multiple targets may make contributions to individual target fits. It is our estimation that many, if not most of the targets in the target report are very large projectiles or GP bombs. This would be an ideal area for conducting an underwater survey with the marine MTADS system. Comparison of the data sets would be very instructive.

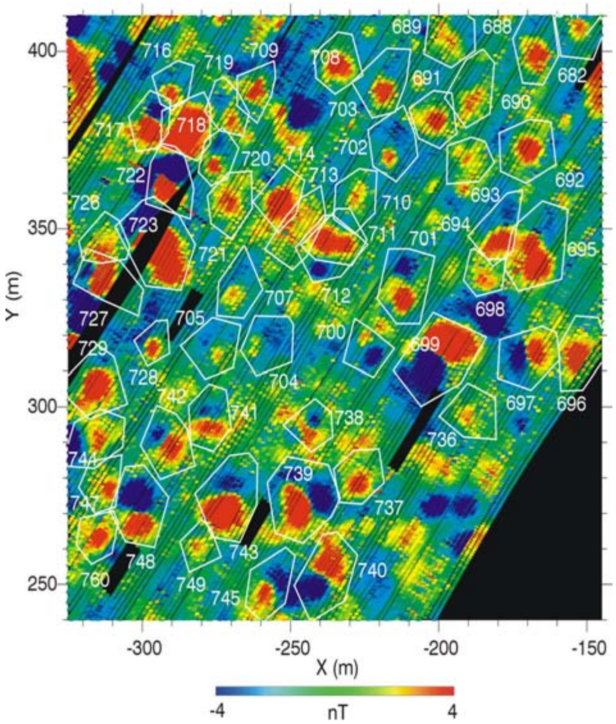

Figure 21. Pixel Image (subsampled) **of an Area Near the South End of the Offshore Range Showing Individual Target Signatures.**

6.2 PERFORMANCE CRITERIA

These demonstration surveys were intended to evaluate the performance of the Airborne MTADS in a series of relatively small surveys at ordnance ranges and impact areas with various types, sizes, and densities of ordnance and OE (and non-OE) clutter. Performance goals as stated in the original test plan were based on detection of inert seed targets at the Airfield, the dewatering ponds, the Active Recovery Field, and the offshore range. IDA personnel evaluated the results of the data analyses submitted by the demonstrators; see Section 4.7 of Airborne UXO Surveys Using the MTADS. The portion of the offshore range that was surveyed did not contain seed targets, nor did the Mine, Grenade, and Direct-Fire Range. The detection performance discussion below is based on information provided by IDA in their analyses of the target reports. IDA evaluated the relative detection efficiencies and location accuracies and biases of the two airborne systems.

In addition to evaluating the ability of the airborne systems to detect UXO in a variety of settings, the demonstrations were intended to evaluate the relative survey production efficiencies of the platforms, the system deployment strategies and efficiencies, the data processing and preparation approaches, the target analysis efficiency and accuracy, the ability of the systems to distinguish between intact UXO and clutter, the relative abilities of the demonstrators to create survey products that could support a realistic UXO remediation, and the ability to create geographically based and GIS-compatible survey products. Also, survey costs and cost efficiencies were to be evaluated and compared. The larger surveys on the offshore range and the Mine, Grenade, and Direct-Fire Range, in addition to providing information to APG about relative contamination levels on the ranges, enabled system evaluation against some of the objectives that were not specifically target-related.

The performance information from the IDA reports, addressed in Section 4.7 of Airborne UXO Surveys Using the MTADS, was presented effectively without comment. In the following sections, we readdress each of the sites that had seed targets, then discuss the additional targets that were dug at Active Recovery Range from lists prepared by IDA using the MTADS and Oak Ridge Airborne Geophysical System (ORAGS) target reports. Performance evaluation criteria include those described above and system detection sensitivity, accuracy of location and depth predictions, and navigation system performance.

6.3 PERFORMANCE ASSESSMENT

6.3.1 Performance at the Airfield

In Section 4.6.8.2 of Airborne UXO Surveys Using the MTADS, we reported that, at the request of the ESTCP Program Office, we extended the analysis of the airfield data. The original analysis assumed that the smallest UXO of interest were 60-mm mortars. In the reanalysis, we were directed to report all targets down to the size limit (signal-to-noise limit) of detection. Our original target report contained 308 targets; the expanded analysis contained 610 targets. In Section 4.7.1 of Airborne UXO Surveys Using the MTADS, we presented tabular data and ROC curves prepared by IDA showing the MTADS' detection and characterization performance. IDA analyses were based on our expanded list containing 610 targets.

In the original analysis containing 308 targets, two of the three 60-mm and fourteen of twenty-one 81-mm mortars were correctly reported. The 105-mm projectiles were all detected; one of the projectiles (NRL Target No. 248, StringID PAF-105MM 1A) was reported 10 cm beyond the 1.0-m detection halo.

In the expanded analysis (610 total reported targets), the final 60-mm mortar was reported, as were four additional 81-mm mortars. This left three 81-mm mortars undeclared. In each case (NRL Target Nos. 572, 191, and 259), declarations were recorded; however, the signatures of the larger objects masked those of the 81-mm seed targets, causing a seed-target miss in each case.

The original analysis, which involved 308 targets, captured 44 of the 52 (or 85%) of the seed targets, including all the 105-mm projectiles. The false-alarm rate for this analysis was then six digs for each recovered seed target. The 302 additional targets in the expanded report captured 5 additional seed targets. Only one of the five was a target with a fit that converged. The four remaining targets were unanalyzable items mechanically marked in dense clutter consisting primarily of large targets. Digging these targets might recover the additional five seed targets; however, it is debatable whether the analysis really isolated these seed targets. Unless they are specifically instructed to "dig the flag," EOD personnel, digging targets in the field typically orient themselves with a metal detector to begin their operation. If the dig team felt their mission was to dig the large target (either specified by our dig list or with guidance from their metal detector), once they recovered the large target, they may or may not, recover the nearby smaller seed target.

Digging all targets in the expanded target report would lead to a false-alarm rate of 11.5 digs per recovered seed target. If all targets were dug, the final probability of detection (Pd) would be 94%, and three 81-mm projectiles would be left in the field. At this point, it is a matter of

conjecture whether the originally submitted Airfield dig list or the expanded dig list represents the better survey work product.

The detection efficiency of the Airborne MTADS at the Airfield (using either dig list) was exceptionally high. The missed targets on the expanded dig list were undetectable because they were buried in the footprint of much larger targets. These results, on their face, would indicate that the MTADS could be used to detect 60-mm and 81-mm mortars. The Airfield was an unusual situation, however; the results cannot be extrapolated to other sites. This site is very flat, the background clutter density (except in the area of the buried utilities) is relatively low, and geological interference is nonexistent. There is no significant vegetation on the site—It looks much like a golf course fairway. For these reasons, we were able to fly the survey at an unusually low altitude, and, because the site is very small, we also flew it very slowly. As was pointed out in the IDA report, our data density at the APG Airfield was about three times higher than is typical of many of our larger airborne surveys.

6.3.2 The Active Recovery Field

As described in Section 4.7.2 of Airborne UXO Surveys Using the MTADS, the seed target detection efficiency at the Active Recovery Site was vanishingly small. The evaluation provided in Table 13, which shows five correctly declared targets within a 1.5 m radius, is misleading. Examination of the target analyses for these five targets shows that three of the five NRL declarations were accidental, resulting from analyzed objects that were much too large to be the implanted seed targets. The Active Recovery Field survey area is much too contaminated with very large ferrous objects to enable detection of the seed targets. The massive signatures of the very large objects effectively screen the returns from the much smaller seed targets. The density of large targets and their overlapping signatures require that target analysis be done on a much less sensitive scale than on any of the other sites in this demonstration.

Conducting UXO surveys on a site with the conditions of Active Recovery Field is a waste of resources. UXO geophysical surveys should be conducted only following removal of heavy equipment, hardware, and movable obstacles such as the packing crates and blast screens. Moreover, a preliminary surface clearance should always be conducted on a site as contaminated as this one. Even assuming that these steps have been taken, geophysical surveys (if UXO clearance is the goal) on a site such as this will always have to be done several times. In each survey and clearance cycle, efforts should be concentrated only on the largest targets in dense areas; more sparsely contaminated areas can be more comprehensively cleaned in each cycle. To confidently clear an area like this range would require several sequential survey and clearance operations (at least three, following the initial surface clearance).

We declared ≈ 3,000 targets in the Active Recovery Field dig report. Conducting the target analysis for this site using the MTADS routines and preparing the target report and required graphics products were very time-consuming; the realistic cost was >$12,000. This far exceeds the original survey cost for the site. Searching for the seeded 81-mm and 105-mm targets on this range, without first removing the existing contamination, was shown to be an effectively impossible task.

To increase the value of the Active Recovery Field study, IDA worked with personnel from APG, ATC, and ESTCP to develop a selective dig list of additional (pre-existing) targets for remediation. The MTADS and ORAGS target reports were sorted to establish common target picks. These were down-selected to targets that were relatively isolated from interferences and to targets assigned relatively high UXO probabilities. The dig list prepared by IDA contained 291 targets. The ATC dig list was pared to 218 targets during the process of digging. Of the targets in the ATC list, 29 were not dug because they were offshore (or for other placement reasons), or the results were lost or were inconclusive. The final dig report is presented in the project final report. Recovery of these items provides a more meaningful evaluation of the MTADS and ORAGS surveys because they sample the inventory of targets that characterize the true UXO threat on this range. Of the 189 dug targets with a documented record, 91 were either intact UXO or substantial parts of UXO items. This dig program resulted in slightly fewer than 2.1 digs per recovered UXO. Even though this was not a comprehensive, random sampling of the primary dig lists, the false-alarm rate was very low.

6.3.3 The Dewatering Ponds

A total of 47 seed targets were emplaced in the five ponds, including 81-mm mortars and 105-mm and 155-mm projectiles. The edges of the ponds, particularly of the large pond, were heavily contaminated with large ferrous clutter items. The banks of the large pond were about 2 m above the water level, making it hard to survey at low altitude near the shoreline. The ponds were reported to be about 2 m deep, but this has not been verified. Table 15, derived from the IDA report, shows the detection efficiency for the MTADS survey. The MTADS target report contained 224 targets. It was noted in the NRL submission that about one-half of the reported targets are outside the shorelines of the ponds or are much too large to be 155-mm projectiles. These targets were included in the target list in case APG wishes to investigate them sometime in the future.

The coordinates and identifications of the seed targets are provided in Table 16, which also provides information on the targets that were detected in the MTADS survey.

The 81-mm mortars were uniformly undetectable. All of the 105-mm and 155-mm projectiles were detected in the small ponds; only a fraction were detectable in the large pond. Of the unreported targets in the large pond, most were missed because their signals were too small. One target (FP-105MM 2) was missed because its easting coordinate had been recorded incorrectly in the target report. A few of the targets were missed because their signals were buried by the very large signal returns from the edges of the large pond. In addition, it is possible that a few of the targets may have had their coordinates recorded incorrectly or that they were inadvertently moved. This is postulated because, in a few cases, appropriate signals were observed in somewhat displaced positions from the reported coordinates (e.g., P-105MM 12, P-155MM 1, P-155MM 2).

The helicopter altitude above the large and small ponds was very similar. It is likely that the majority of the targets were missed in the large pond because the water was deeper than in the smaller ponds.

6.4 TECHNOLOGY COMPARISON

Some aspects of the relative performances of the ORNL and NRL systems have been treated comprehensively by an unbiased analyst in the IDA reports. For more detail, see NRL's Airborne UXO Surveys Using the MTADS and the corresponding ORNL report (currently in draft form). These reports, in final form, will be posted on the ESTCP documents Web site.

Production cost information at APG based on the NRL demonstration is not representative because it was effectively a local operation. By comparison, ORNL mobilized helicopters from Canada and personnel from Tennessee.

Cost information derived from this operation is not appropriate for evaluation of the Airborne MTADS also because of:

- The small sizes of the survey areas
- The difficult access resulting from onerous security requirements
- The impracticality of the Active Recovery Field and offshore impact range sites from a UXO survey point of view
- The requirement of reanalyzing data to size limits far below that dictated by ordnance requirements
- The extensive documenting and reporting requirements that far exceed what would be required on any realistic UXO survey/remediation operation.

7.0 ISLETA PUEBLO DEMONSTRATION DESIGN

7.1 PERFORMANCE OBJECTIVES

The demonstration design for this project included three overlapping surveys.[22] The first was a vehicular magnetometry survey of 100 acres near the previously identified bull's eye, S1, on the Pueblo of Isleta near Albuquerque, New Mexico. The vehicular survey was to be followed by an Airborne MTADS magnetometry survey of 1,500 acres centered on the bull's eye and including the vehicular survey area. Finally, the MTADS survey was to be followed by an airborne survey by ORNL of the same 1,500 acres. The selected survey areas are shown in Figure 22. First-order control points were established by a commercial surveyor, GeoMetrics GPS, Inc., to support this project and other projects. The coordinates of the corner points of the vehicular and airborne surveys are provided in Table 17. It was specified by the ESTCP Program Office that the processing and analysis of the vehicular survey data be handled entirely independently of the airborne data.

Based on an earlier surface inspection of the area by a senior UXO supervisor, the primary targets expected on this range included M-38 and BDU-33 practice bombs. A small amount of heavy-walled shrapnel was observed, consistent with air-dropped GP bombs. In addition, the ESTCP Program Office specified that an array of inert ordnance be emplaced in the vehicular survey area by ERDC, working with the ESTCP Program Office.

The vehicular results were used as a benchmark for the two airborne surveys. Consequently, the demonstration test plan[22] specified that the targets within the vehicular survey were to be analyzed and fit. In practice, as discussed below, only ≈ 69.5 of the planned 100 acres were completely surveyed by the vehicular MTADS. The vehicular and airborne survey teams independently analyzed their data, prepared prioritized target lists, and submitted the results to ESTCP and the IDA at the conclusion of the surveys as Excel spreadsheet target reports.

From these analyses, IDA prepared an inclusive dig list. NRL provided oversight to EOTI, Inc., a commercial UXO remediation firm, in the reacquisition of targets on the dig list. After reacquisition and flagging of the targets on the dig list, they were excavated. As they were uncovered, targets were relocated using GPS. All target parameters were documented, and the ferrous objects were photographed.

The primary objective of these demonstrations was to produce a quantitative comparison of the airborne systems to each other and to benchmark their performance compared to the vehicular MTADS. A second objective was to evaluate the airborne systems' performance against individual targets, including the ability to distinguish UXO from OE scrap and pre-existing clutter.

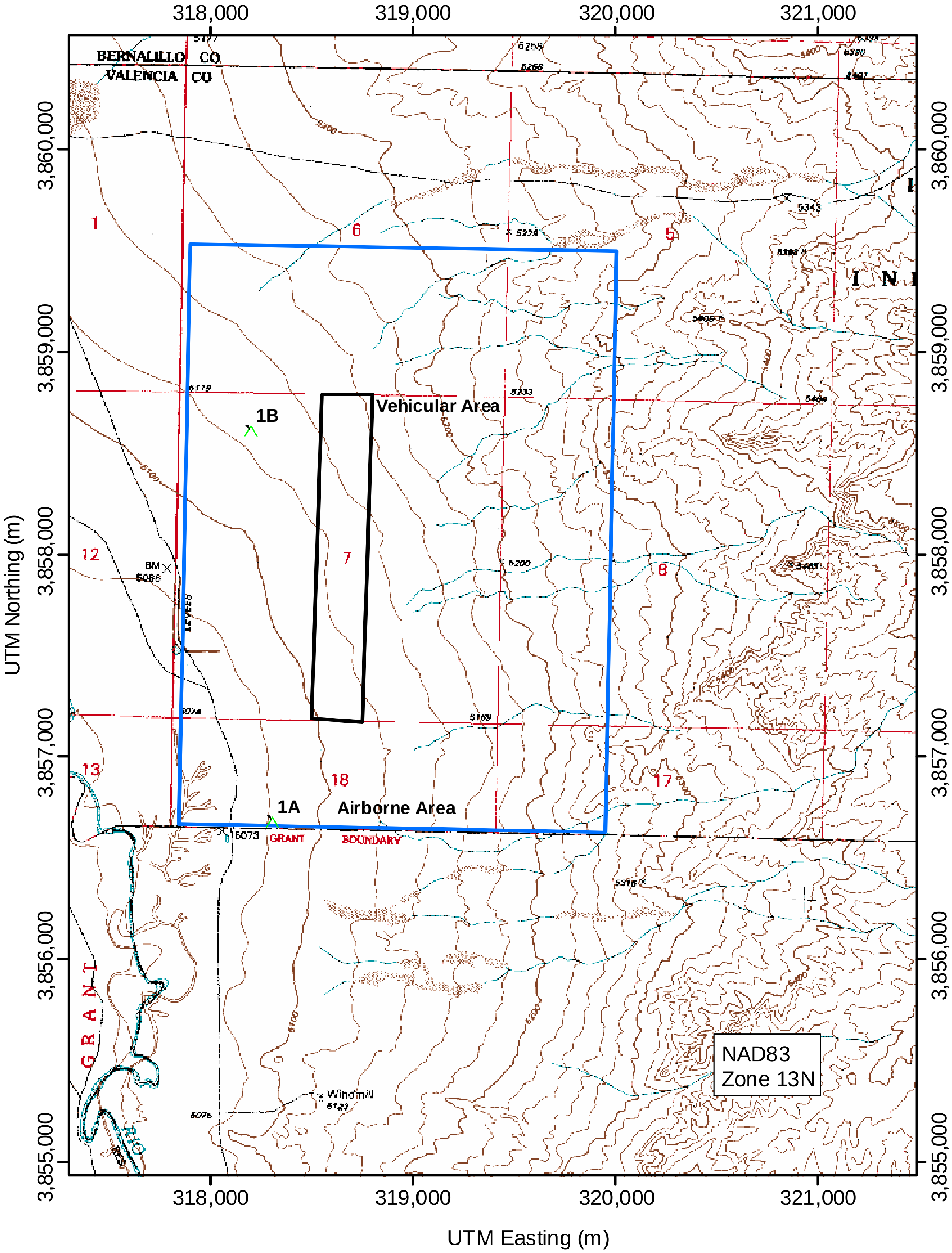

Figure 22. A Portion of a U.S. Geological Survey (USGS) Topographic Map Showing the Boundaries of the Planned Surveys. (The locations of the two first-order points installed on this site for the surveys are shown as 1A and 1B.)

Table 17. Coordinates for the corners of the survey areas.

Point	Latitude	Longitude	Northing (m)	Easting (m)
			NAD 83	
Air-NW	34° 51' 42.726"N	106° 59' 31.494"W	3,859,534.87	317,901.48
Air-NE	34° 51' 42.972"N	106° 58' 08.556"W	3,859,500.82	320,007.88
Air-SE	34° 50' 09.696"N	106° 58' 08.724"W	3,856,627.06	319,947.15
Air-SW	34° 50' 09.576"N	106° 59' 31.632"W	3,856,664.97	317,840.93
Vehicle-NW	34° 51' 18.912"N	106° 59' 05.400"W	3,858,788.00	318,549.62
Vehicle-NE	34° 51' 19.038"N	106° 58' 55.650"W	3,858,786.99	318,797.32
Vehicle-SE	34° 50' 26.694"N	106° 58' 56.400"W	3,857,174.63	318,746.38
Vehicle-SW	34° 50' 26.940"N	106° 59' 06.294"W	3,857,187.19	318,495.20

7.2 SELECTING THE TEST SITE

The survey boundaries for this demonstration were chosen by the ESTCP Project Office in conjunction with the Environment Department of the Pueblo of Isleta. The S1 range was chosen ahead of others on the Pueblo because it is of most concern to the Tribe. It has the greatest probability of containing live dud ordnance, and it offered the opportunity to survey the largest area with the available resources.

7.3 TEST SITE CHARACTERISTICS AND HISTORY

7.3.1 Site Characteristics

The Pueblo of Isleta is located approximately 10 miles south of Albuquerque in north-central New Mexico. The Reservation is bordered on the north by the Sandia Military Reservation, which includes Kirtland Air Force Base, the Manzano Mountains on the east, and the Rio Puerco and the Laguna Pueblo Reservation on the west.[17]

The site consists of relatively flat terrain; it is primarily desert grassland with the elevation increasing from 5,100 ft on the west to 5,400 ft above sea level at a broken escarpment on the east.

7.3.2 Site History

The area referred to as Site B in the Draft Site Assessment Report,[17] which contains target S1, comprises an area of approximately 7,000 acres. This land was leased from the Tribe in the 1950's for use as a bombing range for aircraft from Kirtland AFB. Documentation in Bureau of Indian Affairs' files indicates that the area was used as a practice bombing range from 1956 to 1961, primarily for training with fast aircraft during bombing runs. In the 1960s, Kirtland collected and piled surface ordnance debris on site for removal. Up to two tons per acre of practice bombs and ordnance scrap were removed, but there is no record of intact explosive ordnance recovery.

7.4 PHYSICAL SETUP AND OPERATION

7.4.1 Predemonstration Activities

The vehicular MTADS and components of the airborne system were mobilized to the target S1 site using a rented 53-ft trailer, Figure 23. The MTADS tow vehicle, the magnetometer trailer, and vehicular and airborne components, spares, and supplies were also transported in the trailer. The helicopter was ferried to the site by Helicopter Transport Services from their FBO hanger at the Martin State Airport in Baltimore, Maryland.

Figure 23. The MTADS Base Camp for the Isleta Demonstration (showing the office and garage trailers, generator, diesel tank, and transport trailer)**.**

NRL rented all logistics supplies, facilities, and equipment from firms in Albuquerque. One trailer was used exclusively for data processing and analysis, as a communications center, for battery storage and charging stations, as an electronics repair station, and for storing spares and supplies. A second 8 ft × 48 ft trailer, which could be opened from either end, was used as a garage and for secure storage of the MTADS vehicle and sensor platform. A diesel field generator provided power to the trailers. Fuel storage was provided for the generator, and portable toilets were provided for staff. Figure 23 shows the MTADS base camp. Aviation fuel to support the airborne survey was also located on site.

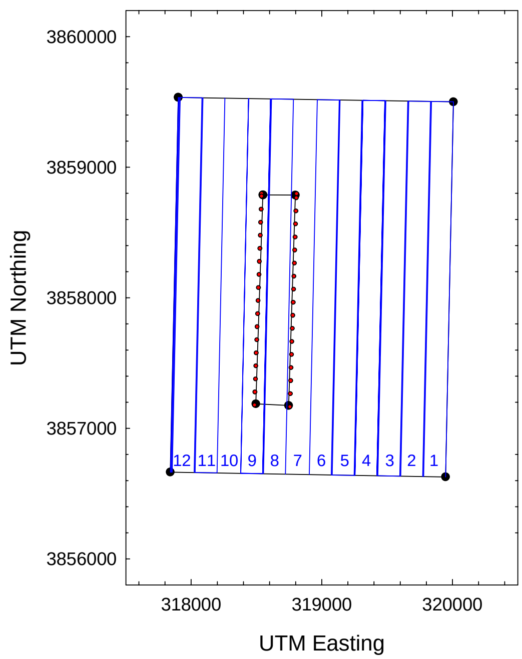

Figure 24. Planned Layout of the Isleta Airborne Survey. (The planned vehicular MTADS survey bounds are shown in black.)

7.4.2 Period of Operation

The NRL portion of the demonstration was accomplished February 19–27. The start of the survey was delayed 2 days due to snow on the East Coast that closed area airports for several days. The vehicular survey was terminated earlier than planned because of equipment failure. The survey log for the airborne survey is given in Table 18 and for the vehicular survey in Table 19. The airborne survey area was divided into 12 sorties of 25 survey lines each (175 m east to west). These sorties and their relation to the vehicular site are shown schematically in Figure 24.

Table 18. Survey Log and Production Information for the Airborne MTADS Survey.

Date	Activity	Survey File Name	Duration (min.)
Wednesday 2/19/03	MTADS personnel arrive at site, unpack trailer, and set up office. Transport airborne components to Belen, NM, airport and assemble sensor boom.		
Thursday 2/20/03	Aircraft arrives in Albuquerque. Mate survey hardware to aircraft.		
Friday 2/21/03	Ferry aircraft to Belen. High winds prevent survey. Test flight conducted late in the day.	03053004	14
Saturday 2/22/03	Replace mag sensor #6.		
	Survey tracks 1–15 of sortie 7.	03054001 30354002	49 34
	Survey vehicular site (tracks 23–25 of sortie 7 and all of sortie 8).	30354003 30354004 03054005	56 59 51
Sunday 2/23/03	Survey all of sortie 9.	03355003 03355004 03055005	61 20 60
	Survey tracks 15–23 of sortie 7.	03055006	51
	Test flight for eastern edge of site. Track 1 of sorties 1 and 2.	03055007	14
	Survey all of sortie 3.	03055008 03055009 03055010	44 42 44
	Survey tracks 1–17 of sortie 4.	03055011 03055012	24 57
Monday 2/24/03	Survey tracks 15–25 of sortie 4.	03056001	47
	Survey sortie 5.	03056002 03056003 03056004	45 43 29
	Survey sortie 6.	03056005 03056006 03056007	61 19 37
	Survey tracks 1–10 of sortie 10.	03056008	47
Tuesday 2/25/03	Survey tracks 8–25 of sortie 10.	03057001 03057002	60 17
	Survey sortie 11.	03057003 03057004 03057005	39 45 28
	Survey sortie 12.	03057006 03057007 03057008	43 50 23
	Survey sortie 13.	03057009 03057010 03057011 03057012	45 9 45 34
	Resurvey tracks 11 and 12 of sortie 3.	03057013	15
	Remove equipment from aircraft. Aircraft departs site for ferry home.		

Table 19. Survey Log and Production Information for the Vehicular MTADS Survey.

Date	Activity	Survey File Name	Duration (min.)
Monday 2/24/03	Static test.	03055001	26
	Site survey.	03055002	55
Tuesday 2/25/03	Site survey.	03056001	31
		03056002	28
		03056003	58
		03056004	60
		03056005	58
	Calibration area.	03056006	61
	Site survey.	03056007	17
		03056008	55
		03056009	58
Wednesday 2/26/03	Site survey.	03057001	58
		03057002	19
		03057003	59
		03057004	50
		03057005	29
		03057007	58
		03057008	15
		03057009	57
		03057010	31
	Calibration area infill.	03057011	2
	03056004 infill.	03057012	4
Thursday 2/27/03	Site survey.	03058001	60
		03058003	61
		03058004	61
		03058005	63
		03058006	58
		03058007	52
		03058008	30
	Sensor boom delaminates, survey terminated.		
Friday 2/28/03	Pack equipment for shipment. MTADS personnel depart site.		

7.4.3 Area Characterized

The vehicular MTADS survey covered 28.1 hectares (≈ 69.5 acres), including a 10 m buffer beyond the survey boundary; see Figure 25. The vehicular analysis spreadsheet contained 1,364 targets including 16 calibration targets that were planted near the northern edge of the site. Target analyses used the six-category probability classification scheme. The vehicular picks are given in Table 20.

Table 20. Vehicular MTADS target picks for the Isleta vehicular survey area.

UXO Classification	Calibration Targets	1	2	3	4	5	6	Total
Number of picks	16	305	328	322	239	137	17	1,364

The Airborne MTADS surveyed 570 hectares (1,408 acres). The terrain and tree cover on the two easternmost sorties would have required a survey at greater than 3 m above the ground. Flying at this altitude would have compromised our ability to detect the M-38 and BDU-33 ordnance that were the expected targets of the survey. As the MTADS was flying the survey, the ORNL team was still surveying on the eastern area above the treetops. To maximize the useful survey data for the Tribe, we deleted sorties 1 and 2 (see Figure 24) and added a new sortie on the western edge of the site. This enabled us to cover almost to the western edge of the Tribal land associated with target S1.

Airborne UXO targets were picked in two areas. The first area was part of the 100-acre site that was surveyed by the vehicular MTADS (see Figure 25); the analyzed area did not include the densest area of the bull's eye. The targets were picked and the target list submitted to ESTCP before the vehicular survey began. Later, the ESTCP Program Office requested that the airborne analyst pick more targets by analyzing areas closer to the bull's eye. In response to this request, the airborne analyst, who was not on site during the vehicular data collection and had no access to the vehicular data, expanded the analyzed portion of the 100-acre site. This resulted in a target list containing 1,260 picks, which are categorized in Table 21. The analyzed airborne survey area is contained in the two smaller yellow rectangles north and south of the bull's eye, as shown in Figure 26.

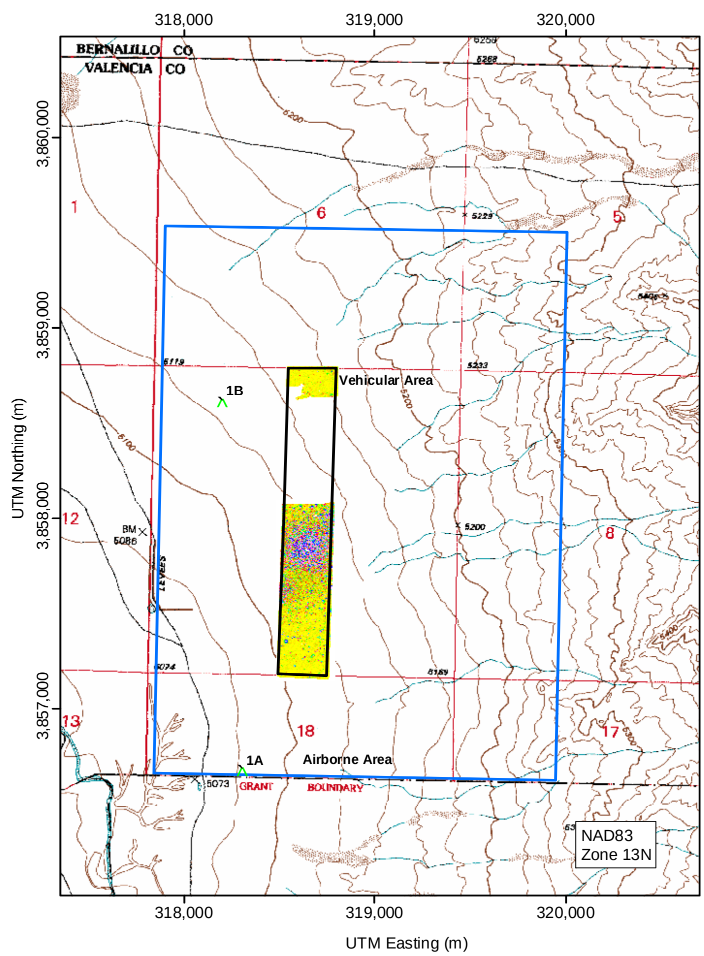

Figure 25. Magnetic Anomaly Map from the Vehicular MTADS Survey Superimposed on the USGS Topo Map of the Area.

Table 21. Airborne MTADS Target Picks Sorted by Classification.

UXO Classification	Calibration Targets	1	2	3	4	5	6	Total
Vehicular area picks	12	502	336	282	42	69	17	1,260
Primary area picks		93	85	70	48	52	40	388

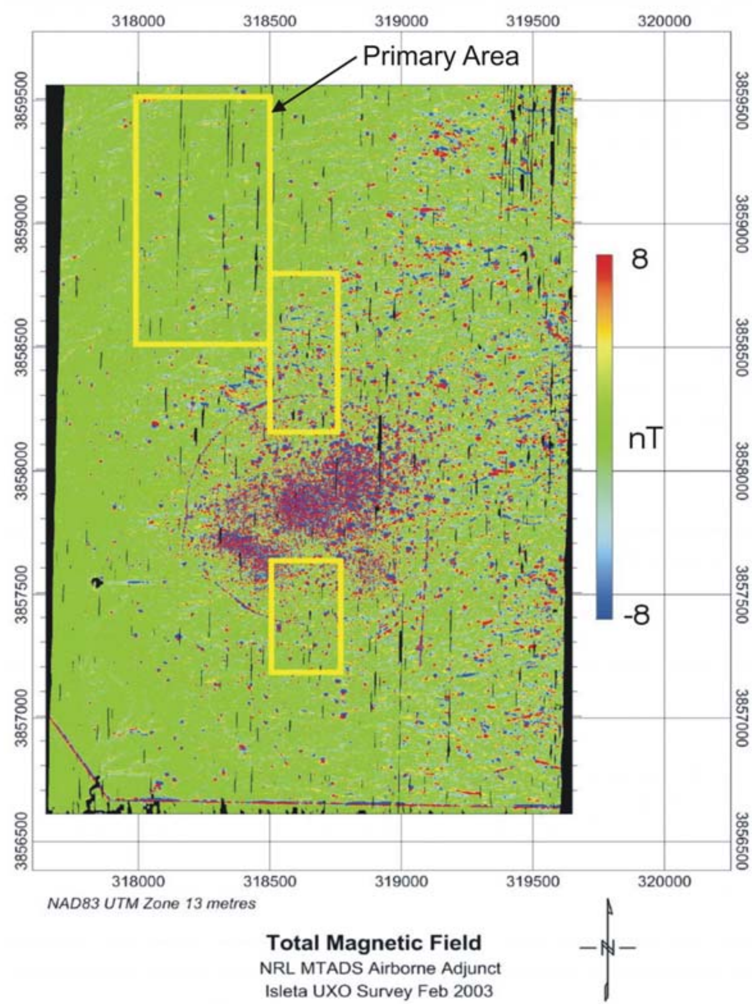

Figure 26. Magnetic Anomaly Map of the Isleta Airborne Survey. (The vehicular survey areas are outlined by the smaller yellow rectangles. The primary area is outlined by the large yellow rectangle.)

7.4.4 Areas Remediated

Targets were remediated in the areas described above as the vehicular area and the Primary Area. The perimeter of the vehicular area is bounded in black in Figure 25, which also shows the actual area covered by the vehicular survey. In Figure 26, the remediation areas are shown bounded in yellow. The larger Primary Area was surveyed only by the airborne systems. Targets were remediated in two parts of the vehicular area contained within the smaller yellow rectangles in Figure 26.

7.4.5 Operating Parameters for the Technology

The Airborne MTADS survey production data is presented in Table 18. Table 22 summarizes the helicopter use information. Staging the helicopter at the Belen airport and establishing a Jet A fuel tanker on the survey site minimized local ferry times and costs. The ORNL survey team was still surveying on February 22 when our production survey operations began. All Airborne MTADS survey operations were completed between February 22-25. The survey production rate was 1,408 acres/24.1 hours or 58.4 acres/hour, based on actual survey time, or 49.9 acres/hour, including the local ferry and test hours.

Table 22. Helicopter Use Time, Based on the Pilot Log.

Date	Mobilize/ Demobilize	On Survey	Local Ferry/Test	Total
	Hrs	Hrs	Hrs	Hrs
Feb 18-20	15.6			15.6
Feb 21			1.3	1.3
Feb 22		4.2	0.5	4.7
Feb 23		7.0	1.0	8
Feb 24		5.5	0.5	6
Feb 25		7.6	0.6	8.2
Feb 26 - Mar 1	16.8			16.8
Total log hours	32.4	24.3	3.9	60.6

7.4.6 Survey Experimental Design

A strict arm's-length relationship was maintained between the NRL vehicular and airborne surveys. The vehicular data processor (who was also the target analyst) was resident on the survey site during the vehicular survey operations. The airborne data processor (a different person) was resident on the survey site only during the airborne survey. The airborne survey operations in the vehicular survey area (sorties 7, 8, and 9) were completed before the vehicular survey began, and the data were handed off to the airborne target analyst, who was never present on the site. The airborne target analysis of the 100-acre vehicular area was completed and the target list submitted to ESTCP and IDA before the vehicular survey began. Subsequently, the ESTCP Program Office requested that the survey analysis area be extended to include areas closer to the bull's eye. The expanded target list was resubmitted to ESTCP and IDA; this is the data summarized in Table 21.

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8.0 ISLETA PUEBLO PERFORMANCE ASSESSMENT

8.1 PERFORMANCE DATA

The 100-acre vehicular demonstration area was surveyed by the airborne system as part of the entire site, as shown in Figure 26. All airborne survey lines followed the 3,000-m north-south traverses. Conversely, the vehicular survey was conducted using 250-m east-west traverses. Figure 27 shows a 60 m × 90 m area about 1,000 m north of the bull's eye common to both surveys. This 1.3-acre area contains five of the seed targets—one 81-mm mortar (yellow circle) and four 105-mm projectiles (yellow pentagons). In addition, an Mk-76 practice bomb (target 250 in the airborne survey) is shown in the yellow rectangle. Targets are much denser nearer the bull's eye. After the ESTCP Program Office requested that the airborne analysis be extended to include areas closer to the bull's eye, a total of 28 ha (≈ 69.5 acres) was analyzed. The expanded target report contained 1,364 entries encompassing the area that included all the emplaced seed targets.

The vehicular MTADS system broke down during the survey, leaving 30.5 acres of the intended area unsurveyed. The area surveyed by the vehicular system included only 47 of the 112 emplaced seed targets.

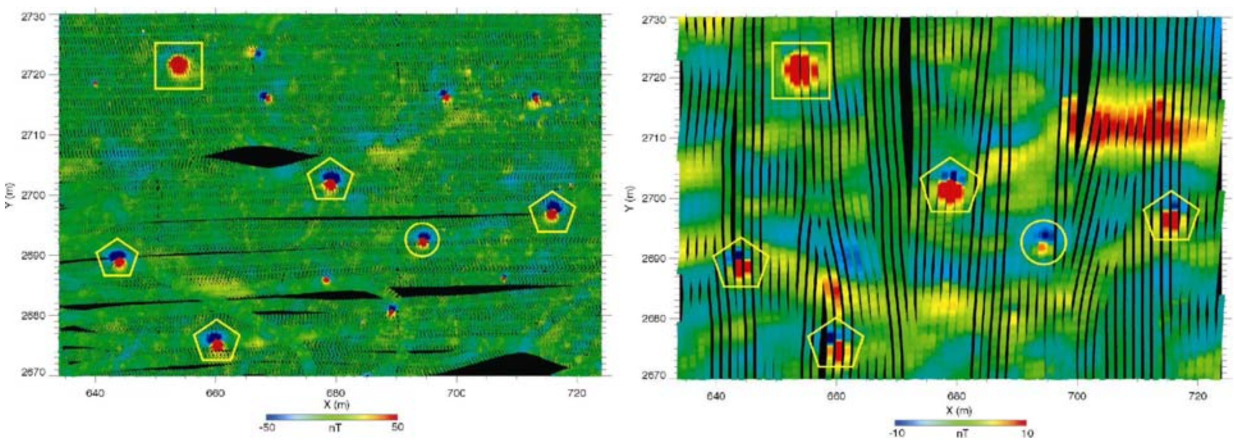

Figure 27. Magnetic Anomaly Images from the Airborne Survey (on the left) **and the Vehicular Survey** (on the right)**.**

8.2 PERFORMANCE CRITERIA

The airborne demonstration was evaluated from three different perspectives following the evaluation criteria used in the IDA report:[23]

- The airborne systems' performances were evaluated against the emplaced seed targets by using the vehicular survey as a benchmark. This enabled comparison of the relative performances of the two airborne systems and comparison of the vehicular and Airborne MTADS systems (see Section 8.3.1).

- Extensive targets were dug in the vehicular survey area that were common to all three survey systems. All category 1 and 2 targets from the vehicular survey area were dug, in addition to a few large Airborne MTADS targets. There were 338 recovered items in these two categories. Relative system performances are discussed in Section 8.3.2.
- In the analysis region (see Figure 26) referred to as the Primary Area, 161 items were dug that were common to the NRL and ORNL surveys. These items were chosen largely from the category 1 and 2 targets on the NRL and ORNL dig lists. The results are discussed in Section 8.3.3.

8.3 DATA ASSESSMENT

8.3.1 Performance Against Emplaced Targets

Table 23, adapted from the IDA report, shows the types and numbers of seed targets that were implanted and the numbers that were detected by the three surveys. The evaluation assumes a radius of 1.5 m around the target to qualify as a detection. This radial area is referred to as the detection halo. The vehicular MTADS target list had 104 items, and the Airborne MTADS (covering a larger area) had 165. Since the airborne system was not designed to detect reliably ordnance smaller than 2.75-in warheads, IDA expunged the 60-mm mortars from the list before constructing detection ROC curves. Figure 28 shows ROC curves, which are an adaptation from the IDA report based on a 1.5-m detection halo and the exclusion of the 60-mm mortars from the seed target database. The Airborne MTADS detected 77% of the larger 2.75-in and 105-mm ordnance.

Table 23. Emplaced Ordnance Detection by Type for a 1.5-m Halo.

Ordnance	Total Implanted	Airborne MTADS	Vehicular MTADS
2.75 in	12	11	2 of 2
60 mm	20	4	6 of 6
81 mm	40	19	20 of 21
105 mm	40	29	17 of 18
Total	112	63	45 of 47

An unexpectedly large fraction of the 105-mm targets was not successfully detected in the Airborne MTADS analysis. These were missed for a variety of reasons. Two of the 105-mm seed projectiles were outside the analyzed survey area. The remaining nine were missed because of geological interferences or because their signals were too small to measure due to orientation, burial depth, or helicopter altitude. The target density as the bull's eye was approached became much higher, and target signals began

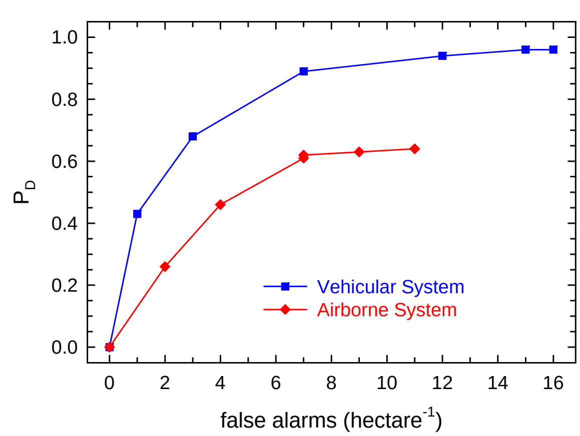

Figure 28. ROC Curves for Emplaced Ordnance Detection for a 1.5 m Halo.

to merge in the Airborne MTADS data set. This required that the analysis display scale be expanded, which resulted in loss of the lower-signal targets.

The mean of the target location accuracy of the Airborne MTADS was < 6 cm, and the standard deviation was ≈ 30 cm. Figure 29 shows a scatter plot for the location error for the seed targets. These data, of course, reflect both the accuracy of the target emplacement operation and the location accuracy of the survey and analysis processes. The very small values for the locus of the errors indicate that there is no significant offset bias in either of the processes. The target location accuracy of ≈ 30 cm is consistent with the Airborne MTADS performance at other sites.

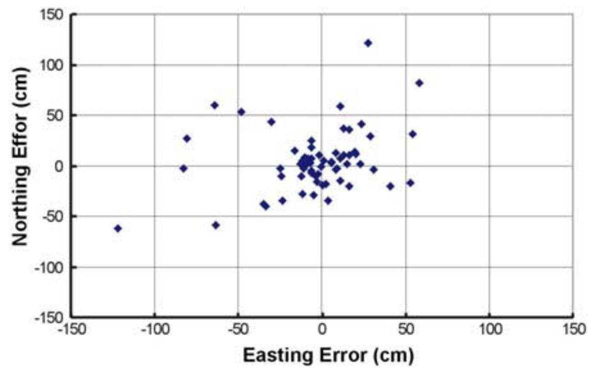

Figure 29. Airborne MTADS Location Error Scatter Plot for the Seed Targets for a 1.5 m Halo.

8.3.2 Vehicular Area Remediated Targets

A dig list was developed to support recovery of targets from the area surveyed and analyzed by each of the three survey systems. The list is comprised primarily of targets from categories 1 and 2 of the vehicular MTADS dig list. About a dozen targets categorized as large bombs were added from the Airborne MTADS dig list.

The IDA report considered the results of 272 digs from this list. Only a fraction of the targets labeled as very large and deep on the Airborne MTADS list were dug because of the time required to exploit the large, deep targets. Of the six targets dug that did not appear on the vehicular MTADS dig list, three were 500-lb or 1,000-lb bombs and three were categorized by the dig team as "nuclear simulator shapes." In the IDA report, the dug targets were divided into the five categories shown in Table 24. Figure 30 shows the IDA ROC curves for the system performances based on a 1.5-m halo. The detections and background alarm rates are based on 1,136 declarations by the Airborne MTADS team, and 1,237 by the vehicular MTADS team. In this figure, both intact ordnance and ordnance-related scrap are categorized as ordnance detections.

Table 24. Results of the Ordnance Remediation Operation in Vehicular Survey Area.

Vehicular MTADS Classification	Intact Ordnance	Ordnance Related Scrap	Nonordnance Related Clutter	Geology "Hot Dirt"	Empty Hole
1	53	160	7	1	0
2	6	27	4	2	0
4	0	1	0	0	0
Total	59	188	11	3	0

There is an excellent correlation between the MTADS airborne and vehicular versions of the dig lists that compose this list of remediated targets, in part because the dig list was prepared from

category 1 and 2 targets from the vehicular list. If both the "intact ordnance" and "ordnance-related scrap" categories are included as ordnance, they constitute 94.6% of the list; 23% of the dug targets on the list were intact UXO.

The remediated targets were located with GPS when they were uncovered so their locations could be precisely determined. They were photographed and either removed or blown in place if it was decided that they should not be moved. Determining the locations of the targets as they were recovered enabled an evaluation of the location accuracy of the MTADS surveys and analyses. Figure 31 shows the distribution. These plots bin the detections into a histogram and show the distribution and 90% and 95% recovery points. The location accuracies are somewhat lower than those attained for the seed targets. This is understandable because most of the targets on this dig list were large; many were broken up or were located in the midst of clutter from bomb fragments.

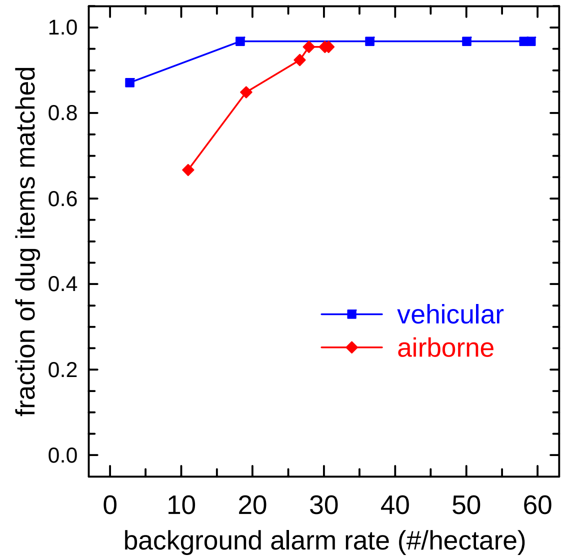

Figure 30. ROC Curves for Targets Remediated in the Vehicular Area for a 1.5 m Halo.

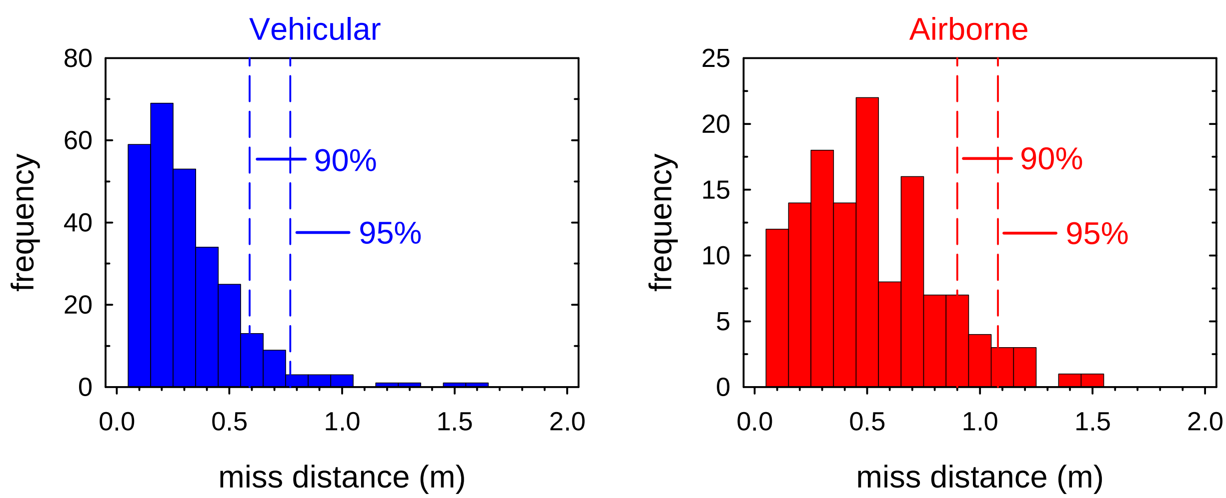

Figure 31. Histogram Plots Showing Location Accuracies of the Vehicular and Airborne MTADS Remediated Targets in the Vehicular Area (using a 1.5 m halo)**.**

8.3.3 Targets Remediated in the Primary Area

A dig list was prepared from the category 1 and 2 targets from the MTADS and ORNL target reports for the Primary Area. NRL reported 366 targets in this area. In the Primary Area, a total of 338 targets, which had been reacquired with GPS, were dug and photographed. Figure 32 shows the IDA ROC curves for these digs, assuming a 1.5-m halo. Scoring was done twice,

once with only intact ordnance contributing to detection and once with both intact ordnance and ordnance scrap contributing to a positive declaration. These are identified as case 1 and case 2 in Figure 32. Table 25 shows the target location error statistics for these recovered targets. The location accuracies are similar to those for the targets dug in the vehicle survey area.

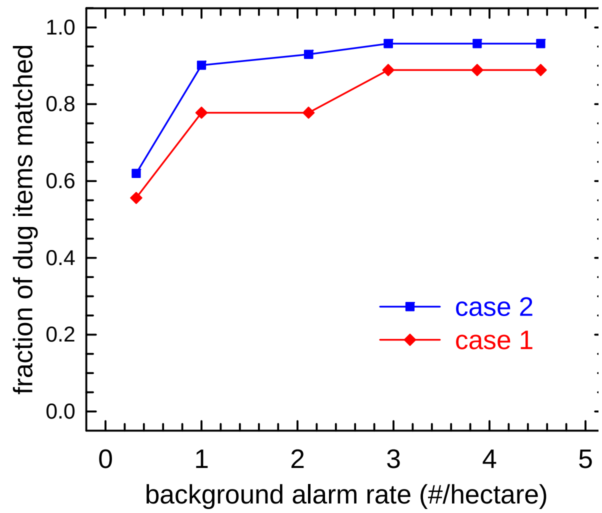

Figure 32. ROC curves for the targets remediated in the Primary Area for a 1.5 m halo.

8.3.4 Reinvestigation of "No Finds" in the Primary Area

Of the 318 targets that were remediated in the Primary Area, 196 appear on the NRL target report. Of these 196, 61 were negative finds, i.e., declared as either "empty holes" or geology/hot dirt. Because the dig results reported an unusually high proportion of empty holes, and because very few digs in the vehicular area were declared as empty holes it was decided to selectively reinvestigate a portion of the empty holes. Both the NRL and ORNL airborne analysts were asked to suggest a list of 20 empty holes that merited reinvestigation.

Table 25. Location Error Statistics for the Primary Area for a 1.5-m Halo.

	Mean Error (cm)		Std. Dev. (cm)	
System	**North**	**East**	**North**	**East**
Airborne MTADS	5	9	31	30

A new investigation list was prepared from the NRL and ORNL suggestions, and these targets were reinvestigated using the NRL man-portable magnetometer system. Reinvestigated targets with a positive signal response were dug again; 22 NRL airborne targets were redug. As a result of these redigs, one BDU-33 was recovered, one hole was found to contain metallic OE scrap, and six holes were found to hold metal scrap that was not OE. The remaining holes were declared to contain magnetic soil/hot rocks or to be empty. Many of the geology returns produced signatures in the original analysis that very closely approximated UXO targets.

8.4 TECHNOLOGY COMPARISON

Certain aspects of the relative performances of the ORNL and NRL systems have been treated comprehensively by unbiased analysts in the IDA reports. More information is available in the Isleta demonstration reports prepared by each team. See NRL's Airborne UXO Surveys Using the MTADS and the corresponding ORNL demonstration report, which is still in draft form. These reports will be posted on the ESTCP documents Web site.

Table 26 compares performances in detecting emplaced targets for the vehicular and airborne MTADS for a 1.5 meter halo; corresponding IDA ROC curves are shown in Figure 28. Table 26 provides the mean location errors and standard deviations for each system.

Table 26. Location Error Statistics for the Vehicular Area Using a 1.5-m Halo.

	Mean Error (cm)		Std. Dev (cm)	
System	**North**	**East**	North	**East**
Airborne MTADS	2	6	39	35
Vehicular MTADS	1	6	26	25

Figure 32 plots the ROC curves for the airborne system for targets remediated in the Primary Area. Location error statistics for the same area are provided in Table 25.

Direct comparison of the detection efficiencies of the vehicular and Airborne MTADS systems for the seed targets is not particularly informative as the vehicular system broke down after covering only 47 of the 112 seed targets and the vehicular system was designed to detect the 60- and 81-mm mortars (≈ 54% of all the seed targets) while the Airborne MTADS was not. The Airborne MTADS correctly reported approximately 50% of the 81-mm mortars and 77% of the larger seed targets. The average target location accuracy for the airborne system was ≈ 30 cm for the detected seed targets, which is consistent with the prior demonstrations.

In the three-system, common-area dig list prepared primarily from the vehicular category 1 and 2 targets, the detection efficiencies of the vehicular and airborne MTADS systems were indistinguishable, as shown in the ROC curves in Figure 30. The relative location accuracies were ≈ 26 cm and ≈ 36 cm for the vehicular and airborne systems for all 258 of the digs that contained metallic objects.

The relative production costs for the vehicular and Airborne MTADS surveys are treated in detail in the final report, Airborne UXO Surveys Using the MTADS. In that report, we developed a cost estimate for a 1500-acre survey, typical of the Isleta survey described in Sections 7 and 8 of the same report. The costs were developed to compare an airborne survey with a similar vehicular survey. It is assumed that mobilization is from the East Coast to the New Mexico site. The preparation and startup costs, which include site visits, establishing control points, development of a Test Plan and a Health and Safety Work Plan, are the same for the two approaches. Mobilization and demobilization, on-site logistics, and survey support costs are appropriate for each survey. Target analysis is based on an assumed 10,000 targets, with the only survey reporting being preparation of a target report suitable for target reacquisition and support of digging operations. The airborne survey is assumed to take 4 survey days, with two days of setup, teardown, calibration, and training. The vehicular survey is presumed to require 75 survey days (for a single survey system). Operations are assumed to occupy a 5-day week with maintenance and repair taking place on weekends. Actual target analysis is assumed to take place off site. The costs, presented in Table 27 and summarized by survey and support activities, are organized somewhat differently from the data in Tables 34 and 35 of the final report. Fuel, labor, charter costs, and on-site logistics are considered as survey costs in Table 27. On-site

setup, tear down, calibration, and training costs are considered as mobilization/demobilization costs, as are equipment shipping costs and rentals to support site logistics. Data analysis and preparation of dig sheets and reports are considered as survey costs. This breakdown is more consistent with the way that UXO geophysics surveys are bid and costed.

The last two rows in Table 27 are the total survey costs or costs/acre, the latter for adding survey acres to the hypothetical survey. These costs are unrealistic for projecting commercial survey costs as they do not include allowances for equipment capitalization or amortization, provision for fee, or allowances that are always required to support QA operations and required QC follow-ups. Depending on the circumstances, these cost factors might double the actual costs to conduct the survey. The costs in Table 27 do not include provisions for weather delays, labor stoppages, change orders, or stop-work orders. These provisions are typically negotiated as separate clauses in UXO survey bids.

We have conducted several airborne surveys similar to that addressed in Table 27. The costs, as projected, are realistic with the caveats cited in the previous paragraph. We have never conducted a vehicular survey nearly this extensive. It is unlikely that a 15-week vehicular survey could be conducted without significant down time for unscheduled maintenance, emergency repairs, or other unforeseen contingencies. Indeed, during this demonstration, the vehicular system broke down before completing 70% of the 100-acre survey, causing the vehicular survey to be terminated. The surface topography of this site was more rugged than that in the previous BBR or APG demonstrations; however, it was not atypical of many of the U.S. western desert ranges.

Table 27. Comparison of Survey Costs (in $K, except where indicated) **for 1,500-Acre Vehicular and Airborne MTADS Surveys.**

Preparation and startup costs		**Airborne Survey**	**Vehicular Survey**
	Site visit/inspection	6	6
	Test plan, maps, photos	15	15
	Establish control points	8	8
Total startup costs		29	29
Mobilization/demobilization costs			
	Equipment to and from site	4	21
	Helo charter, pilot, fuel	26.9	
	Helo charter for setup/teardown	3	
	Equipment repair/restock	2	10
Total mobilization/demobilization costs		35.9	31
Survey costs			
On-site logistics	Equipment rental	2	
	Electrical	2	10
	Fuel (diesel and gasoline)	1	1
	Materials	2	10
	Office, storage, trailers, toilets		6
Survey operations	Charter	20.2	
	Rental vehicles	2	30
	Fuel	3	3
	Labor/per diem	21.7	253.3
	Hazardous waste operation (HAZWOPR) labor		45
	Airfare	2	10.7
Data analysis, survey products		20	20
Total survey costs		75.9	389
Nominal survey costs ($/Acre)		50.60	259.33
Grand total		140.8	449

9.0 COST ASSESSMENT

9.1 COST REPORTING

In Tables 10 and 11 in Section 4 and Table 27 in Section 8, we presented cost analyses for hypothetical 1,500-acre UXO surveys with conditions similar to the demonstrations conducted at the BBR Impact Area and the Isleta S1 target range. The survey costs were comparatively developed assuming Airborne MTADS and vehicular MTADS surveys. It was assumed that the UXO survey products would eventually support UXO clearance operations. However, no provision was made for costs of resurveys that would be associated with QA operations or QC follow-up. The former costs are typically billed by the contractor as part of the UXO survey, and the QC follow-up invariably requires additional geophysical studies. These costs are highly variable, depending on the particular site, its level of existing contamination, and anticipated UXO clearance. Because of these uncertainties and because it is likely that the commercial airborne UXO surveys will be used most extensively for footprint reduction, we have not attempted to tackle these issues.

We have also not treated the capital equipment as part of the cost equation. Equipment costs will have to be treated very differently for equipment supporting airborne and vehicular surveys, even though there is much commonality between the systems. For illustration, assume that an application involves a 10,000 acre UXO survey. At 100 acres per week for a single vehicular system, this would require about two years of survey work. It is very likely that the entire vehicular field system would have to be capitalized for this one application, and moreover it would require substantial additional (but unpredictable) maintenance and repair costs. The same 10,000 acre survey with the Airborne MTADS would require 5 or 6 weeks at 400 acres per day. Assuming the pilot avoids catastrophic interaction with the terrain, the wear and tear on the airborne survey equipment should be minimal. A single airborne system operating 40 weeks per year should be able to survey 80,000 acres. If this level of business could be generated, the amortization costs of the airborne equipment could be well under $10/acre, even if the system was amortized over a 1-year period.

Table 28 shows the projected capital equipment costs associated with producing a new production system of each type. These costs are based on our experience in the development of the vehicular and Airborne MTADS platforms. The initial cost outlays to acquire the systems are very similar. We assume that the helicopter supporting the airborne platform is chartered, which moves that expense to a direct survey cost. The vehicular platform tow vehicle is assumed to be a John Deere Gator or equivalent all-terrain vehicle (ATV). This cost is substantially less than the cost of the MTADS or Surface Towed Ordnance Locator System (STOLS) tow vehicles. Given our experience with these tow vehicles, we feel that the costs associated with the very low ferrous content vehicles can be avoided because platform signatures can be largely dealt with in data processing. The tow vehicles will, however, have to be rugged enough for extended use, capable of sheltering the computers and electronics from the weather, and able to carry batteries sufficient to support all-day operation of the survey equipment. Transportation costs for the entire vehicular survey system are likely to be substantially more than shipment costs for the airborne components but less than the ferry costs for the charter

helicopter. In each case, these costs are associated with mobilization and costed separately from per-acre survey costs.

Table 28. Capital Equipment Cost Comparisons in $K for Airborne and Vehicular UXO Survey System.

	Airborne System			Vehicular System		
Component	Unit Cost	Platform	Spares	Unit Cost	Platform	Spares
Sensors/mag	25	175	50	25	175	50
Sensors/other	30	30	10	10	10	5
Sensor platform	40	40	40	80	80	10
Support vehicle*				10	10	5
Vehicle/interface mods	10	10	5	15	15	10
DAQ hardware	40	40	20	30	30	20
Sensor-DAQ interface	10	10	10	20	20	20
Navigation	60	60	5	60	60	5
DAS hardware	30	30	10	30	30	10
Software licenses	6	6	0	6	6	0
Tools and specialized field support equipment		10	5		10	5
Shipping containers		30	10		30	10
Capital equipment and spares costs			606			626

*Airborne support vehicle is a chartered helicopter.
Vehicular platform is towed by a customized John Deere Gator NP 4X4 Trail ATV.

9.2 COST ANALYSIS

The cost drivers are very different for Airborne MTADS and vehicular MTADS UXO surveys. Vehicular towed array survey costs are dominated by labor costs. In the hypothetical 1,500-acre vehicular survey described in Table 27, more than 70% of the actual survey costs are labor and per diem costs. An additional 15% of the ancillary survey costs (airfare, rental vehicles, fuel, toilets, etc.) are indirectly associated with personnel on site. The fraction of the survey costs associated with labor would be somewhat lower for much smaller surveys, which could be completed with fewer field support staff and which would not require crew rotations.

The comparative labor costs to support the same survey with the airborne equipment are slightly over 30% of the vehicular equipment costs. Data analysis and creation of survey products were not included in these comparisons as their costs are identical for both surveys. The primary airborne survey cost drivers are associated with the charter and support costs for the helicopter system, which are about 30% of the actual survey costs. The fraction of the airborne survey costs associated with the helicopter will remain relatively constant for surveys larger than ≈ 1,000 acres.

9.3 COST COMPARISON

In this study, we have concentrated primarily on comparisons between the vehicular and Airborne MTADS and, by extension, on hypothetical commercial systems derived from these systems' designs. Table 27 points out that preparation and startup costs, mobilization and demobilization costs, and data analysis and creation of survey product costs are very similar for the airborne and vehicular systems, even though there are differences in individual component costs. The demonstrations at the Impact Area of the BBR and at target S1 of Isleta have projected that vehicular survey costs on a per-acre basis are about 400%-600% higher than costs on the same sites using the airborne system. These estimates are also supported by other airborne surveys conducted with the MTADS and by many additional surveys conducted with the vehicular MTADS. These cost comparisons do not include equipment capitalization and amortization costs.

Table 28 shows that capital equipment costs would be similar for creation of new airborne and vehicular array systems based on the MTADS designs. Realistically, the vehicular capital equipment costs should be amortized over 5,000 acres of surveys (50 weeks at 100 acres/week). Based on the costs in Table 28, this would add approximately \$125/acre to the vehicular survey costs. It seems reasonable to assume that the airborne system, being subject to less wear and tear, could be amortized over 2 years of work. If enough work could be captured to support the equipment at 200 days per year, equipment costs could be amortized over 160,000 acres, which would add about \$4.25/acre to the cost of the surveys.

The key driver in overall UXO remediation costs is the cost of excavation of individual items that pose no UXO risk to health or safety. These costs, depending on the prior use of the range and its potential future uses, may be 60%–90% of the total site cleanup costs, with all the geophysics operations being only 10%–20% of the costs. Therefore, the ability of the geophysics survey and analysis to exclude harmless UXO fragments and other ferrous scrap from the dig list may outweigh the cost advantages of inexpensive surveys. Table 11 in Section 4.4.3 of this report considered this issue for the BBR demonstration. At this range, we concluded that about 50% more targets would have to be dug behind an airborne survey than behind a vehicular MTADS survey. At this relatively sparsely populated range with relatively large UXO, we still predicted a 60%-70% cost advantage for an airborne survey and remediation. The results at the APG survey were not extensive enough to make these extrapolations.

The results at the Isleta S1 survey indicated that remediation based on an airborne survey would leave some undetected UXO in the field that would be detected by a vehicular towed array. However, in the three-system common survey area, based on the number of targets picked and the ability to discriminate between UXO and scrap, cleanups following either the NRL airborne or vehicular system would require that similar numbers of targets be dug from either analysis. In this scenario, a site cleanup based on an airborne survey would be several times less expensive.

The technology deployment comparisons that we made looked at tradeoffs between the use of the vehicular and Airborne MTADS (or their commercial equivalents). In reality, there are very limited circumstances in which these technologies should be competitively pitched against each other. The vehicular system should be considered when (1) the survey areas are relatively small (a few dozen to a few hundred acres) or (2) the site is known to be densely contaminated with a

wide range of ordnance sizes that must be comprehensively cleared. The airborne survey system should be considered primarily when (1) the survey areas are relatively large (several hundred to thousands of acres), (2) large areas need to be evaluated for footprint reduction, or (3) site conditions will not support foot or vehicular traffic. We anticipate that in many large UXO survey areas, the most economical deployment of equipment will involve use of both airborne and vehicular systems. The airborne system can be used for wide area coverage to identify areas that must be very carefully analyzed for comprehensive clearance. These areas could then be addressed by some combination of vehicular and/or man-portable equipment. In areas involving very shallow water, swamps, marshes, or wetlands, the only practical survey alternative may be the airborne system. UXO clearances in these areas will be very expensive.

10.0 IMPLEMENTATION ISSUES

10.1 COST OBSERVATIONS

The largest single factor affecting the Airborne MTADS survey costs and production rates is the cost of operating the survey helicopter on site. During recent surveys, charter costs have been approximately $700 per hour with a guaranteed 4-hour daily minimum over the duration of the charter. Mobilization of the aircraft to and from the site, originating from its home base, is charged at the hourly charter rate. To maximize production and minimize cost, surveys should be arranged with long survey lines to minimize the time spent in turns. Frequent examination of data quality minimizes time spent taking unusable data. Minimizing time lost in refueling aircraft by having fuel available on site and basing aircraft strategically to minimize daily ferry trips to and from the survey site can represent large increases in productivity and decreases in production cost.

The take-home message from our demonstrations is that it is unlikely to be economical to undertake Airborne MTADS surveys of less than a few hundred acres. Mitigating circumstances occur when UXO surveys must be done over water, in marshy wetlands, or in other areas where one can neither walk nor drive. In these situations, performance issues may override cost issues.

Other steps to maximize productivity for the Airborne MTADS survey of the target ranges were taken at the BBR, APG, and Isleta demonstrations:

- At APG, permission was obtained from Bell Helicopter to allow the helicopter to refuel with JP-8 (the military equivalent to Jet A).[19] Jet A was not available at the Airfield. Refueling with JP-8 therefore required no ferry time. Refueling took place either between survey sites or when downloading survey data for inspection.
- At APG, the helicopter was chartered from Helicopter Transport Services from their Fixed Base Operator (FBO) hangar at Martin State Airport (approximately 20 minutes' flying time from APG).[16] The platform and electronics were assembled and mounted on the helicopter at Martin State Airport. Spares were stationed on site to provide quick recovery, if necessary.
- At all demonstration sites, one-hour missions were flown and the resulting data provided to analysts on the ground for inspection.
- At all three demonstration sites, survey missions were set up in advance on the DAQ computer. This enabled us to switch between survey sites, as necessitated by weather or logistics (e.g., sharing survey ranges with the other demonstrators) by simply starting new survey files.
- At the Isleta demonstration, a long ferry was required originally to bring the helicopter to the area. Rather than basing the helicopter at the Albuquerque airport, we based it at a small municipal airport nearer the target range to decrease daily ferry time to and from the site.[17] A fuel tanker truck was chartered and placed on the impact range for refueling.

- All surveys were planned to start at sunup (or when weather allowed access) and end at sundown each day, with brief pilot rest breaks each hour and a 45-minute break for lunch.

10.2 PERFORMANCE OBSERVATIONS

Unlike the vehicular magnetometer system, the airborne system is not capable of detecting the smallest classes of buried UXO at depth. While the magnetic signals are spatially spread and diminished in intensity with the sensors farther above the ground, our modeling results indicated that, at an altitude of 2 m above the ground, the system should be capable of detecting BDU-33s or Mk 82s in all geologies and ordnance targets equivalent to or larger than 2.75-in warheads in geologically quiet areas. This has been borne out by the demonstrations described in this report. At the geologically quiet and topologically flat prove-out site at the Airfield, we were able to detect efficiently both 60-mm and 81-mm mortars.[16,22] At the much more highly cluttered and geologically active Isleta range, in areas with rough ground surface or significant vegetation, we failed to detect several 105-mm projectiles.[17,23]

The extent to which spreading target signatures interfere with each other and are obscured by geological features was carefully evaluated in the first airborne demonstration at the BBR.[15] In that study, with relative large UXO targets (105-mm to 8-in projectiles) relatively sparsely distributed on the site, detection efficiency for individual UXO was equivalent for the airborne and vehicular towed arrays. Because of the lower data density and the more widely spread anomaly signatures, it proved more difficult to discriminate between UXO and clutter signatures from the airborne data than from the vehicular data. At some APG sites,[16] significantly more targets would have to be dug behind an airborne survey than behind a corresponding vehicular survey. At the Isleta site, if we were cleaning UXO from areas near the bull's eye, more targets would have to be dug following an airborne survey than would be necessary from a vehicular survey. This results from the much higher target densities and the more complex mix of UXO threats on some of these ranges that result in merging and overlapping of adjacent target signatures. The cost tradeoffs between digging more targets and reduced survey production costs are (and always will be) site specific, depending on the types of UXO challenges, the relative density of targets, geological and topological conditions, and the size of the survey site. On all sites in areas of high OE concentration, such as around bull's eyes, or areas with both large and very small ordnance threats, multiple cycles of survey and dig will be required to accomplish an effective clearance.

On large, open sites, such as the Impact Area of the BBR or the S1 target at Isleta, the Airborne MTADS routinely completed 400 acres per day using a two-man field crew. On the very small cluttered and vegetated sites at APG with careful survey planning, we were still able to achieve production rates of 30–40 acres per survey hour. The Airborne MTADS is a very productive UXO survey platform.

10.3 SCALE-UP

The end user of the Airborne MTADS technology is most likely to be one or more of the large architectural and engineering (A&E) firms that do substantial amounts of UXO geophysics work. With some consulting cooperation with the original developers, the Airborne MTADS could be straightforwardly replicated for commercial applications. It is our conclusion that the current

MTADS design is appropriate for direct commercialization. It is both rugged and efficient. The weak components were replaced during the shakedown tests. There have been inquiries from some groups about potential consulting help in establishing a commercial capability. The impediments are the substantial capital costs involved in putting a commercial system together and uncertainties about the government's commitment to establishing suitable venues for its use. If a request for proposal (RFP) were issued for a wide-area UXO search (involving several thousand acres), it is likely that there would be multiple responders proposing to bring in airborne geophysics (similar to the Airborne MTADS) as a solution. A large firm would likely want 25,000 acres in assured airborne UXO survey business to feel they could recover their investment costs and potentially make a profit. Capitalizing the entire system cost (see Table 28) over 25,000 acres would add only ≈ $25/acre to the survey costs.

10.4 LESSONS LEARNED

Once the airborne demonstration began on the IA, it took place almost flawlessly. There were few mistakes or failures that could serve as learning experiences. This is in contrast to our experience during the shakedown surveys. There were three shakedown exercises at the Aberdeen Proving Ground separated by 1-month periods. Each was dominated by equipment breakdowns, malfunctions, and misadventures. We recovered and fixed most of the mistakes resulting from each exercise before the next shakedown. These shakedown exercises were critical to the success of the final IA demonstration. It was important that they be separated by at least a month to enable us to evaluate problems, order parts, implement fixes, and plan for the following exercise.

10.5 APPROACH TO REGULATORY COMPLIANCE

The regulatory issues affecting the UXO problem are most frequently associated with the BRAC and FUDS processes involving the transfer of DoD property to other government agencies or to the civilian sector. When transfer of responsibility to other government agencies or to the civilian sector takes place, the DoD lands fall under the compliance requirements of the Superfund statutes. Section 2908 of the 1993 Public Law 103-160 then requires adherence to CERCLA provisions. The basic issues center upon the assumption of liability for ordnance contamination on previously DoD-controlled sites. These regulatory considerations do not apply to active DoD facilities.

The Airborne MTADS is an appropriate technology for addressing the UXO problem in areas where the terrain cannot be traversed on foot, that are dangerous for ground activities, and that are too large to survey economically with vehicular systems. These demonstrations provide data to demonstrate a statistical probability of success for the detection and characterization of isolated bombing targets or impact areas, ordnance burial caches, or individual ordnance, including a range of large projectiles. These considerations are important in establishing the value of this approach and in its ultimate acceptance by regulators and the stakeholder community.

Unless it is necessary to clear vegetation to allow closer access to the ground, it is possible to conduct effectively noninvasive airborne surveys—without coming in contact with the ground at any point on the range. Hence, there is no chance of disturbing cultural or religious artifacts.

Even within active ranges, such as at the APG, environmental concerns must be addressed because soil and groundwater contamination by energetic residues and byproducts, and by heavy metals (As, Bi, Pb, Sb, U, etc.) associated with ordnance components, may migrate to underground aquifers and routinely, through run-off, reach other properties. Specifically at the APG, extensive (on base) wetlands are used by migratory birds and other waterfowl; and marine estuaries and bays beyond the APG boundaries (with known UXO contamination) are continually harvested for finfish and shellfish by private and commercial fishermen.

Conducting UXO geophysical surveys in shallow-water wetlands and in shallow offshore areas is extremely difficult, expensive, and inefficient. The Airborne MTADS provides a technology appropriate for addressing some of these challenges.

These demonstrations enabled us to evaluate the extent to which the Airborne MTADS can be effectively applied in terrains that cannot be traversed on foot and in areas that are dangerous for routine ground activities.

11.0 REFERENCES

1. "Multi-sensor Towed Array Detection System (MTADS)," ESTCP Project UX-9526, Cost and Performance Report, http://www.estcp.org/documents/techdocs/index.cfm.

2. "MTADS Unexploded Ordnance Operations at the Badlands Bombing Range," Pine Ridge Reservation, Cuny Table, SD, July 1997, J.R. McDonald, H.H. Nelson, J. Neese, R. Robertson, and R.A. Jeffries, NRL/PU/6110—98-353.

3. "MTADS Demonstration at the Former Fort Pierce Amphibious Base, Vero Beach, FL, March 1998," J.R. McDonald, H.H. Nelson, R. Robertson, R.A. Jeffries, and Karl Blankenship, NRL/PU/6110—98-372.

4. "MTADS Live Site Survey, Bombing Target #2 at the Former Buckley Field, Arapahoe County, CO, August 1998," J.R. McDonald, H.H. Nelson, R. Robertson, and R.A. Jeffries, NRL/PU/6110—99-379.

5. "MTADS Live Site Survey and Remediation at Bombing Targets N-9 and N-10 on the Laguna Pueblo Reservation," Laguna, NM, August 1998, J.R. McDonald, H.H. Nelson, R. Robertson, and R.A. Jeffries, NRL/PU/6110—00-398.

6. "MTADS Live Site Survey and Remediation on the Walker River Paiute Reservation Adjacent to Bombing Range B-19 at the Naval Air Station Fallon, Schurz, NV, July 1999," J.R. McDonald, H.H. Nelson, and R.A. Jeffries, NRL/PU/6110—00-406.

7. "MTADS Unexploded Ordnance Operations at the Badlands Bombing Range, Air Force Retained Area, Pine Ridge Reservation, SD, September, 1999," J.R. McDonald, H.H. Nelson, R. Robertson, and R.A. Jeffries, NRL/PU/6110—00-424.

8. "Results of the MTADS Technology Demonstration #3, Jefferson Proving Ground," January 1997, J.R. McDonald, H.H. Nelson, R.A. Jeffries, and R. Robertson, NRL/PU/6110—99-375.

9. "Development of Commercial Towed-Array System including a Man-Portable Multi-sensor Towed Array System Adjunct for Survey of Hazardous Metallic Material," Cooperative Research and Development Agreement (CRADA) between Blackhawk Geometrics, Inc. and the Naval Research Laboratory, NCRADA-NRL-98-197, as amended on 14 October 1999.

10. Memorandum of Agreement Between the U.S. DoD and the U.S. EPA, "Management Principles for Response Actions at Closed, Transferring, and Transferred Ranges, Interim Final Draft, March 7, 2000.

11. "Man-Portable Adjuncts for the MTADS, Final Report for ESTCP Project 199811," J.R. McDonald, H.H. Nelson, Thomas H. Bell, and Bernard Puc, NRL/PU/6110—01-434.

12. "Advanced UXO Detection/Discrimination Technology Demonstration. U.S. Army Jefferson Proving Ground, Madison, IN," ERDC/EL TR-01-20, U.S. Army Engineer Research and Development Center, September 2001.

13. "Man-Portable Adjuncts for the Multi-sensor Towed Array Detection System (MTADS)," ESTCP Cost and Performance Report, October 2002.

14. “Airborne UXO Surveys Using Magnetometer Arrays,” ESTCP Project UX-0031, http://www.estcp.org/projects/uxo/200031o.cfm.

15. “Airborne MTADS Demonstration on the Impact Area of the Badlands Bombing Range, September 2001,” J.R. McDonald, David Wright, Nagi Khadr, and H.H. Nelson, NRL/PU/6110—02-453, May 2002.

16. “Airborne MTADS Demonstration at The Aberdeen Proving Ground, July 2002,” J.R. McDonald, David Wright, Nagi Khadr, and H.H. Nelson, NRL/MR/6110—04-XXX, April 2003.

17. “MTADS Airborne and Vehicular Survey of Target S1 at Isleta Pueblo, Albuquerque, NM, 17 February–2 March 2003,” H.H. Nelson, David Wright, Tom Furuya, J.R. McDonald, Nagi Khadr, and D.A. Steinhurst, NRL/MR/6110—04-8764, 31 March 2004.

18. “Airborne MTADS Demonstration on the Impact Area of The Badlands Bombing Range: Technology Demonstration Plan,” The Naval Research Laboratory, 16 July 2001.

19. “Airborne MTADS Demonstration Over Selected Test Sites at the Aberdeen Proving Ground: Technology Demonstration Plan,” The Naval Research Laboratory, 24 June 2002.

20. “Wide Area UXO Aerial Demonstration and Survey: Demonstration Test Plan,” George Robitaille, USAEC, 17 June 2002.

21. “Analysis of Airborne Magnetometer Data From Tests at Aberdeen Proving Grounds, MD, July 2002,” Mike Tuley and Elvis Dieguez, Institute for Defense Analyses, Draft, 6 November 2003.

22. “MTADS Airborne and Vehicular Survey of Target S1 at Isleta Pueblo, Albuquerque, NM: Technology Demonstration Plan,” The Naval Research Laboratory, 17 February 2003.

23. “Analysis of Airborne Magnetometer Data From Tests at Isleta Pueblo, NM, February 2003,” Mike Tuley and Elvis Dieguez, Institute for Defense Analyses, Draft, 10 November 2003.

24. “Feature Based UXO Detection and Discrimination,” ESTCP Project UX-0210.

25. “MTADS Data Analysis System Migration,” ESTCP Project UX-0328.

26. “Electromagnetic Induction and Magnetic Sensor Fusion for Enhanced UXO Target Classification,” ESTCP Cost and Performance Report, Project UX-9812, February 2004, http://www.estcp.org/documents/techdocs/UX-9812.pdf.

27. “Electromagnetic Induction and Magnetic Sensor Fusion for Enhanced UXO Target Classification,” Final Report for ESTCP Project 1998-12, NRL/PU/6110—00-423, June 2000.

28. “Preliminary Assessment/Site Inspection Report, Badlands Bombing Range—Impact Area”; Ellsworth AFB, SD; Draft-Final; U.S. Air Force Air Combat Command; Prepared for U.S. Army Corps of Engineers under Contract No. DACW 45-94-D-0001, Delivery Order 26, Project Number FXBM 98-7006, Rust Environmental & Infrastructure, January 1999.

29. "Standardized UXO Technology Demonstration Sites," ESTCP Project UX-0103 and SERDP Project UX-1300, George Robitaille, http://www.estcp.org/projects/uxo/200103o.cfm

30. http://www.serdp.org/research/UX/UX-1300.pdf

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APPENDIX A

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